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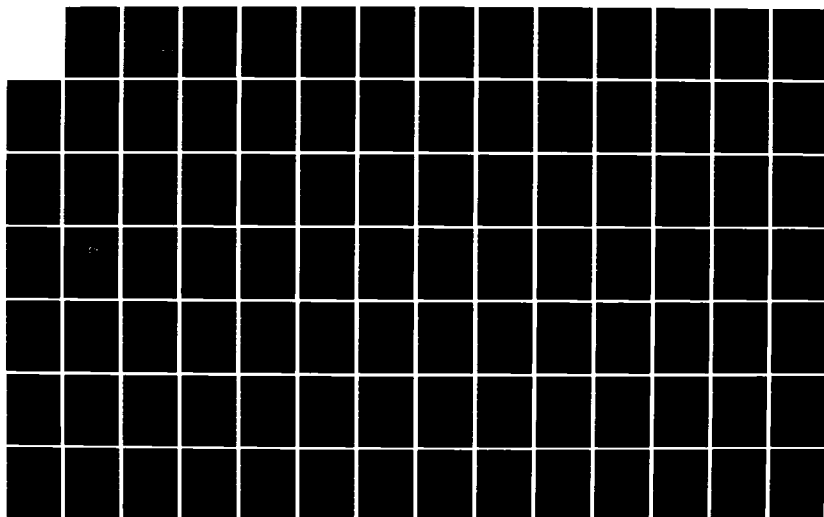
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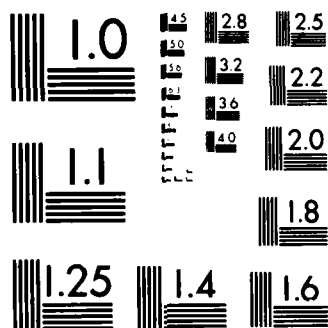
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ENGINEERING AND DEVELOPMENT SUPPORT OF GENERAL
DECON TECHNOLOGY FOR THE DARCOM INSTALLTION
RESTORATION PROGRAM

Task 1. Lagoon/Landfill Liner Compatibility Testing with Explosives
and Trichloroethylene

Gregory M. Gibbons
Jonathan W. Braswell

ENGINEERING-SCIENCE
Two Flint Hill
10521 Rosehaven Street
Fairfax, Virginia 22030

June 1983

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Prepared For:

Commander
U.S. Army Toxic and Hazardous Materials Agency
Aberdeen Proving Ground (Edgewood Area), Maryland 21010

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Synthetic Liners TCE, XR-5, EPDM Neoprene Compatibility Testing Synthetic Liner Materials Hypalon TNT Polyvinyl chloride High density RDX Oil resistant polyvinyl chloride polyethylene PVC, PVC-OR, CPE, HDPE, Chlorinated polyethylene Ethylene propylene rubber		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)		
This report presents the results of liner compatibility screening tests with TNT, RDX and TCE. Using the NSF Liner Compatibility Screening Tests, eight types of liners (PVC, PVC-OR, CPE, Hypalon, XR-5, HDPE, Neoprene, and EPDM) were immersed in TNT, RDX, and TCE solutions for 1 week. Liner and test method selection and data analysis for the screening test are presented.		

SUMMARY

The objective of Task 1 was to document the compatibility of selected synthetic liner materials with the explosives trinitrotoluene (TNT) and cyclotrimethylenetrinitramine (RDX) and the solvent trichloroethylene (TCE). The task scope covered selection of representative liner materials, selection of compatibility test procedures, and laboratory testing of the representative synthetic liner materials. A total of twelve candidate synthetic liner materials were tested using the proposed National Sanitation Foundation Synthetic Liner Waste Compatibility Test Protocol.

The liner testing involved immersion of the candidate liner samples in test chemical solutions at 23°C and 50°C for one week and measurement of the resulting visual, weight and volume changes after one, three and seven days of immersion and after a subsequent 7-day drying period. The visual and weight change data were very reproducible and provided consistent response patterns; however, the volume data were neither reproducible nor provided consistent response patterns. As a result data analyses were limited to the analysis of the visual and weight change data.

Water and temperature were found to have minimal effects on the candidate liners either during the immersion period or subsequent to exposure. The effects of the explosives (TNT and RDX) on the candidate liners were limited, with measured weight changes during immersion of no more than two percent relative to the distilled water controls. All of the candidate liners except HDPE had residual weight gains (five to nine percent) subsequent to immersion in TNT; however, the PVC liners were the only ones to show a weight change subsequent to immersion in RDX - a weight loss of 3.5 percent.

All of the liners were significantly affected by immersion in TCE. Immersion in TCE saturated water resulted in weight increases of between three and 15 percent during immersion. Immersion in water saturated TCE dissolved the CPE and Neoprene liner samples and resulted in weight increases of between 15 and over 200 percent for the other candidate liner samples. Subsequent to immersion in water saturated TCE, weight losses of between 16 and 24 percent were measured for all of the candidate liner samples except HDPE.



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CHAPTER 1

INTRODUCTION

INTRODUCTION

The purpose of this report is to present the findings and results of a preliminary evaluation of the compatibility of synthetic liners with solutions containing the explosives TNT (trinitrotoluene); RDX (cyclotrimethylenetrinitramine); and the chlorinated organic solvent TCE (trichloroethylene). This program included the selection of candidate synthetic membrane liner materials, the selection of liner compatibility testing procedures, and the initial screening of the selected liner materials for compatibility with TNT, RDX and TCE.

BACKGROUND

Until the last decade lagooning was the accepted method of disposal of wastewaters from the manufacture of munitions. As a result, explosive compounds such as TNT and RDX are found in many of the lagoons that have been used by the Army for this purpose. Because these compounds have been defined as hazardous under RCRA, it may be necessary to remove, transport or dispose of the lagoon sediments or the residuals from the treatment of these sediments from many of the lagoons.

It has been assumed that synthetic liners would be used in many of these clean-up operations, but synthetic membrane liners may or may not be compatible with the chemical compounds found in these sediments. Based on existing compatibility data, there was reason to believe at the onset of this investigation that solvents such as TCE would be deleterious to the service life of the commercially available synthetic membrane liners. The available information on the compatibility of synthetic liners with the explosives TNT and RDX was limited and contradictory.

The basic steps of the present investigation were: (1) the selection of representative liner materials; (2) the selection of a compatibility testing procedure; and (3) the compatibility testing of the representative liner materials. A total of twelve candidate liner materials representing eight separate types of liners was selected and used in the test program. The proposed liner compatibility testing procedure of the National Sanitation Foundation (NSF), presented in Appendix B, was used for this investigation. This procedure, described later in the report, has a two-step approach; a screening test of a large number of candidate liners and chemical solutions followed by more extensive testing of the liner or liners

indicated as potentially compatible during the preliminary work. This report is a synopsis of the work effort through the initial screening test.

OBJECTIVES

The general objective of this investigation was to identify commercially available liners warranting further consideration for applications in the treatment, storage, transport and disposal of soils and sediments from munition manufacturing waste disposal lagoons. The specific objectives were as follows:

1. Survey the synthetic membrane liner industry and determine what types of liners are available and determine whether or not they could be used in the intended applications.
2. Identify laboratory methods for compatibility testing of liners and select a test methodology.
3. Prepare and conduct a laboratory test by the selected method of the identified liners using trichloroethylene (TCE), trinitrotoluene (TNT) and cyclotrimethylenetrinitramine (RDX).
4. Based on the results of these tests, identify liners that are potentially compatible with TNT, RDX and TCE.

CHAPTER 2

CANDIDATE LINER SELECTION

BACKGROUND

The synthetic liner industry has a distinct three-step hierarchy, and a knowledge of the organization and flow of goods in the industry is necessary for the selection of the candidate liner for compatibility testing. The three levels in the industry are:

1. Manufacture of resins;
2. Manufacture of roll goods; and
3. Fabrication of sheets

A single company may perform more than one of these functions. Some roll good producers also fabricate sheeting or manufacture their own resin. In general, however, the manufacturing process follows the above sequence.

Synthetic liners are classified by the base polymer. In blends or alloys the main polymer is used for classification. Due to the specific formulation produced by each manufacturer, the properties of one manufacturer's resin may differ from the same type of resin produced by another manufacturer. Resin manufacturers produce the raw materials (polymers) that form the base of the membrane. To the basic polymer (e.g., polyvinyl chloride or chlorinated polyethylene), the resin manufacturers add compounding ingredients specific to their formulation. Compounding ingredients include plasticizers, crosslinking (vulcanizing) chemicals, carbon black, pigments, fillers, biocides, and antidegradents. The resin is sold to a roll good producer or used internally.

Roll good manufacturers use the resin to produce rolls of liner material. The roll good manufacturer will add to the resin additional compounding ingredients specific to his formulation and then form this mixture into rolls of material. The material is either extruded or calendered (rolled) into panels four to six feet wide and of varying length. Roll goods (liners) are produced either with or without reinforcing. Unreinforced (unsupported) liners are calendered or extruded in varying thicknesses. Typical thicknesses for most commercial liners are 15, 30 and 45 mils. Thicker liners are made by plying sheets of material. Reinforced (supported) liners can only be made by calendering. A fabric scrim (weave) is sandwiched between two layers of the membrane material. The normal thickness for a reinforced liner is 36 mils.

Liners are often supplied both unreinforced and reinforced, but some liners, because of the physical properties of the unsupported material, are sold only with reinforcement. For compatibility testing, only unreinforced liner samples are generally used because the exposed fabric scrim allows wicking of test fluid and because reinforcement material changes the tensile properties (tensile strength, ultimate elongation, and S-100 modulus).

Each manufacturer of roll goods adds compounding ingredients for each specific formulation; therefore, the characteristics of liners in the same class may vary from one manufacturer to another. Additionally, the compatibility of different manufacturers' products may differ with a given chemical, temperature and exposure environment. This potential product variation for the same general type of liner makes roll goods the logical selection for initial liner compatibility testing. During initial testing, samples from different manufacturers of each type of liner should be evaluated to determine the similarity between different products.

The final step in construction of most membrane liners is the fabrication of large sheets of material. A sheet fabricator seams rolls of liner material into large panels, often 70 to 100 feet wide and of varying length. The length is dependent on maximum total weight allowed for transport and for ease of installation. The panels are made as large as practical, utilizing as many factory seams and as few field seams as possible. Minimizing the number of field seams facilitates installation. Factory seams are preferable to field seams because they are made under controlled conditions and thus are of better quality.

For high density polyethylene (HDPE), there is no production of roll goods and subsequent factory seaming to fabricate sheets. HDPE sheets are extruded directly at widths of 22-1/2 and 34 feet without seams. These sheets are then seamed in the field during installation.

The seams in a liner often are the weakest point. A full scale test program should include exposure and physical testing of both factory and field seams. Seaming techniques vary with liner material, fabricator and installer preference. A brief definition of the five commonly used seaming techniques follows:

- o Thermal Weld - the process of joining thermoplastic sheets by heating areas in contact with each other to the temperature at which fusion occurs. The process is usually aided by a controlled pressure.
- o Dielectric Weld - a heat weld where the heating is induced within sheets by means of radio frequency waves.
- o Extrusion Weld - a heat weld where molten membrane material is injected into the seam. Extrusion welds are used with HDPE liners.
- o Solvent Weld - the process of joining sheets by applying a solution of the liner compound emulsified in a solvent to areas in contact with each other. The solvent evaporates leaving a homogenous weld of the liner material, usually aided by controlled pressure.
- o Adhesions - the process of joining sheets using specifically formulated glues to form a bond or seal, usually aided by controlled pressure.

LINER TYPES

Liners are classified by the main polymer utilized in their formulation. Table 1 is a description of the ten liner types commercially available today and includes each liner type's commonly used abbreviation. These liners are typically used for lining ponds and lagoons (except for polypropylene). The composition and relative advantages and disadvantages for each type of liner are also summarized in Table 1.

As noted previously, companies in the liner industry can be classified according to the functions they perform. Table 2 is a listing of the major companies involved in the manufacture of liners today. There are 15 firms listed, five of which manufacture resin, nine make roll goods, and eight of which fabricate sheets. Table 2 also indicates the dual function of some companies (i.e., roll good producers who also manufacture resin and/or fabricate sheets). All the companies listed in Table 2 were contacted; detailed information on each manufacturer's products is included in Appendix A, and Table 3 is a listing of the roll good producers (and resin manufacturers) by type of liner.

There are three main producers of roll goods for PVC, PVC-OR, Hypalon and CPE: Mainline; Pantasote; and B. F. Goodrich. Two resin manufacturers supply all the raw materials for Hypalon and CPE: Dow (CPE); and duPont (Hypalon will be made under a duPont patent until 1985). Ethylene interpolymer alloy (XR-5) is produced by only one firm, Shelter-Rite. XR-5 is a patented formulation of Shelter-Rite that reportedly has enhanced chemical resistance properties. EPDM is the only rubber liner material currently produced by more than one roll good manufacturer, namely B. F. Goodrich and Carlisle. Rubber liner materials have been replaced in general usage by the more resistant plastic formulations. A single producer of polypropylene is included: General Tire using Hercules resin. Polypropylene is currently in the developmental stage for use in lining lagoons. It is widely used in tank lining because of its chemical resistance properties; however, it is not a feasible alternative for lining lagoons today.

Table 4 is a summary of compatibility data solicited from roll good producers and sheet fabricators for the test chemicals. The compatibility of liners with the test chemicals is listed in Table 4 as unknown, not recommended or good. There is practically no manufacturer information on compatibilities for TNT and RDX. Only one manufacturer, Stevens, had data on TNT; their compatibility guide listed Hypalon as good for containment of TNT. Generally the solvent TCE is incompatible with synthetic liners. TCE is used with many liners as a surface preparation before field seaming to clean and make the seam area tacky. Table 4 also lists available thicknesses of the liner materials. For testing purposes a common thickness should be used so that a uniform "production grade" sample is used. The most common minimum thickness is 30 mils.

TABLE 1. DESCRIPTION OF POLYMERIC MEMBRANE LINERS CURRENTLY IN USE

TYPE	COMPOSITION	ADVANTAGES	DISADVANTAGES
Butyl Rubber	Co-polymer of isobutylene (97%) and small amounts of isoprene. Usually vulcanized.	<ul style="list-style-type: none"> o High resistance to mineral acids o Good tensile strength o Ozone and weathering resistance o High tolerance to temperature extremes 	<ul style="list-style-type: none"> o Highly swollen by hydrocarbons o Difficult to seam and repair; special vulcanizing adhesive required o Slightly affected by oxygenated solvents
Chlorinated polyethylene (CPE)	25 to 45% chlorine with 0 - 25% crystallinity. Usually unvulcanized.	<ul style="list-style-type: none"> o Resistant to many acids and alkalis o Good resistance to biological degradation o Ozone resistant o Often alloyed with PVC, PE and synthetic rubber 	<ul style="list-style-type: none"> o Swells in high concentrations of aromatic hydrocarbons and oils
Chlorosulfonated polyethylene (Hypalon)	25 to 43% chlorine with 0 - 1.4% sulfur. Usually unvulcanized.	<ul style="list-style-type: none"> o Resistant to acids and alkalis o Ozone resistant o Resists molds and mildews 	<ul style="list-style-type: none"> o Shrinks and hardens from exposure to UV light o Will soften at elevated temperatures o Low tensile strength o Poor resistance to oils o Swells in presence of aromatics

TABLE 1 (Continued). DESCRIPTION OF POLYMERIC MEMBRANE LINERS CURRENTLY IN USE

TYPE	COMPOSITION	ADVANTAGES	DISADVANTAGES
Ethylene propylene rubber (EPDM)	Terpolymer of ethylene, propylene and a minor amount of nonconjugated diene hydrocarbon. Usually vulcanized.	<ul style="list-style-type: none"> o Excellent ozone resistance o Tolerates extremes in temperature o Resistant to dilute solutions of acids, alkalis, silicates, phosphates and brine o Good abrasion resistance 	<ul style="list-style-type: none"> o Not recommended for petroleum, aromatic or halogenated solvents o Special vulcanizing adhesives required for seaming and repair
Neoprene	Generic name of synthetic rubbers based on chloroprene. Vulcanized.	<ul style="list-style-type: none"> o Resistant to oils and acids o Mechanical properties similar to natural rubber with resistance to puncture and abrasion 	<ul style="list-style-type: none"> o Vulcanizing cements required for seaming and repair
Polyethylene (HDPE)	Based on ethylene with 2-3% carbon black, density varies. Unvulcanized.	<ul style="list-style-type: none"> o Superior resistance to oils and solvents 	<ul style="list-style-type: none"> o Special seaming tools required o Clear polyethylene readily degrades on outdoor exposure o Very stiff compared to other liner materials
Polyvinyl chloride (PVC)	Produced from vinyl chloride; 25-35% plasticizers, 1-5% chemical stabilizer, and microbicide added. Un-vulcanized.	<ul style="list-style-type: none"> o Good resistance to many organic chemicals o Good tensile strength and elongation properties 	<ul style="list-style-type: none"> o Affected by UV exposure o Heat of the sun can volatilize plasticizers o Susceptible to attack from hydrocarbons, oils and solvents

TABLE 1 (Continued). DESCRIPTION OF POLYMERIC MEMBRANE LINERS CURRENTLY IN USE

TYPE	COMPOSITION	ADVANTAGES	DISADVANTAGES
Oil resistant polyvinyl chloride (PVC-OR)	Similar to PVC with additional oil resistant compounding ingredients.	<ul style="list-style-type: none"> o Good resistance to many organic chemicals o Good tensile strength and elongation properties o Good oil resistance 	<ul style="list-style-type: none"> o Affected by UV exposure o Heat of the sun can volatilize plasticizers
Ethylene interpolymer alloy	Alloy of elasticized polyolefin.	<ul style="list-style-type: none"> o Resistant to many chemicals o Good oil resistance o Good temperature service o Good weathering 	<ul style="list-style-type: none"> o Not recommended for organics, especially aromatic o Low temperature limitations
Polypropylene	Based on propylene with carbon black added. Unvulcanized.	<ul style="list-style-type: none"> o Resistant to many chemicals o Superior high temperature service o Good low temperature service o Good tensile strength 	<ul style="list-style-type: none"> o Susceptible to UV and ozone attack o Difficult to seam in the field o Not recommended for oxidizing solvents

Sources: 1. Lining of Waste Impoundment and Disposal Facilities, SW-870, USEPA, Office of Water and Waste Management.

2. Engineering and Development Support of General Decon Technology for the DARCOM Installation Program, Task 7. Literature Search and Evaluation of Compatibility Testing of Waste Containment Barrier Materials.

TABLE 2. MANUFACTURERS OF LINERS

MANUFACTURER	CLASSIFICATION		
	Resin Manufacturer	Roll Goods Producer	Sheet Fabricator
Carlisle		X	X
Dow	X		
duPont	X		
General Tire		X	
B. F. Goodrich	X	X	X
Gundle		X	X
Hercules	X		
Mainline		X	
Palco			X
Pantasote		X	
Schlegel	X	X	X
Shelter-Rite		X	X
Staff			X
Stevens		X	
Watersaver			X

Source: Telephone interviews and product brochures

TABLE 3. LINER TYPES AND MAJOR MANUFACTURERS

TYPE	ROLL GOOD PRODUCER	RESIN
PVC	B. F. Goodrich Mainline Pantasote	B. F. Goodrich B. F. Goodrich Pantasote
PVC-OR	B. F. Goodrich Mainline Pantasote	B. F. Goodrich B. F. Goodrich Pantasote
Hypalon (CSPE)	Stevens Pantasote B. F. Goodrich	duPont duPont duPont
CPE	Mainline Pantasote B. F. Goodrich	Dow Dow Dow
HDPE	Schlegel Gundle	Schlegel Phillips
Ethylene interpolymer alloy	Shelter-Rite	Hooker, Ferro
EPDM	Carlisle B. F. Goodrich	Proprietary
Butyl	Carlisle	Proprietary
Neoprene	Carlisle	duPont
Polypropylene	General Tire	Hercules

SOURCE: Telephone interviews and product brochures

TABLE 4. COMPATIBILITY DATA FOR TEST CHEMICALS

Liner Type	Roll Good Producer	Standard Thickness (mils)	Compatibility (Manufacturer's Recommendation)	
			TNT/RDX	TCE
PVC	B. F. Goodrich Mainline Pantasote	10, 15, 20, 30 20, 30 20, 30	Unknown	Not recommended
			Unknown	Unknown
			Unknown	Not recommended
PVC-OR	B. F. Goodrich Mainline Pantasote	30 30 30	Unknown	Not recommended
			Unknown	Unknown
			Unknown	Not recommended
CPE	B. F. Goodrich Mainline Pantasote	30 20, 30 20, 30	Unknown	Not recommended
			Unknown	Not recommended
			Unknown	Unknown
Hypalon (CSPE)	B. F. Goodrich Pantasote Stevens	36, 45 36, 45 36	Unknown	Not recommended
			Unknown	Not recommended
			Good	Not recommended
HPDE	Gundle Schlegel	20, 30, 40, 50, 60, 80, 100 60, 80, 100	Unknown	Unknown
			Unknown	Recommended
			Unknown	Recommended
EPDM	B. F. Goodrich Carlisle	30 30, 45, 60, 90, 120	Unknown	Not recommended
			Unknown	Unknown
Butyl	Carlisle	30, 60, 90, 120	Unknown	Unknown
Neoprene	Carlisle	30, 60, 90, 120	Unknown	Unknown
Ethylene interpolymer alloy (XR-5)	Shelter-Rite	30	Unknown	Unknown

SOURCE: Telephone interviews and product brochures

Table 5 is a summary of the results of a computer data base search performed by the Plastics Technical Evaluation Center (PLASTEC) of the United States Army Armament Research and Development Command (ARRADCOM), Picatinny Arsenal. The PLASTEC data base is a compilation of studies of the compatibility of chemicals, primarily energetics, with plastic materials. Results of each study are listed by PLASTEC as being either compatible, Marginally Compatible, or Incompatible. There were no data for TCE compatibility with the candidate liner types and data for TNT and RDX were limited to PVC, Hypalon, HDPE, EPDM, and Neoprene. For TNT, Hypalon and HDPE were noted in the studies as compatible; however, as noted in Table 5, the studies had conflicting compatibility results for TNT with PVC, EPDM, and Neoprene. For RDX, EPDM and Neoprene were noted as compatible while the studies had conflicting data for PVC and HDPE with RDX.

Table 6 is a listing of the sheet fabricators utilizing the roll good manufacturer's product. Included are the types of factory seam that each fabricator uses and the field seams that are recommended; seaming is similar among fabricators. The widths of the finished sheet, similar among fabricators, are also listed.

LINER SELECTIONS

From the general information on liners and the available compatibility data, six types of liners were selected for testing. Table 7 is a summary of these liner types and the associated roll good producers. Polypropylene was eliminated since it is currently only developmental for the lining industry. Although polypropylene does have good chemical resistance, it is only produced in 4-foot by 8-foot sheets which are an impractical size for lagoon lining.

TABLE 5. PLASTEC COMPATIBILITY DATA SEARCH RESULTS

LINER TYPE	Chemical		
	TCE	TNT	RDY
PVC	No data	Conflicting data	Conflicting data
PVC-OR	No data	No data	No data
CPE	No data	No data	No data
Hypalon	No data	Compatible	No data
HDPE	No data	Compatible	Conflicting data
XR-5	No data	No data	No data
EPDM	No data	Conflicting data	Compatible
Neoprene	No data	Conflicting data	Compatible

SOURCE: PLASTEC, "A Compatibility Data Search, Plastic Materials vs. Energetics", 3 June 1982, ARRADCOM, Picatinny Arsenal

TABLE 6. STANDARD LINER SEAMS AND WIDTHS

Roll Good Producer	Type	Sheet Fabricators	Seams		Width	
			Factory	Recommended Field	Sheet (ft)	Rolls (ft)
Stevens	Hypalon	Staff	Dielectric, solvent weld	Dielectric solvent weld	828	4.6
		Watersaver	Dielectric, solvent weld	Solvent weld	70	4.75
	CPE	Staff	Solvent weld	Solvent weld	100	5.0
		Watersaver	Dielectric, solvent weld	Solvent weld	70	4.75
Mainline	CPE	Palco	Dielectric weld	Adhesive	100	4.6
	PVC	Palco	Dielectric weld	Solvent weld	100	4.5
	PVC-OR	Placo	Dielectric weld	Solvent weld	100	4.5
Harte	PVC	Watersaver	Dielectric, solvent weld	Solvent weld	70	6.3
	CPE	Staff	Solvent weld	Solvent weld	82.8	5.0
Pantasote	PVC	Staff	Solvent weld	Solvent weld	100	5.0
	PVC-OR	Staff	Solvent weld	Solvent weld	100	5.0
Gundie	HDPE	Gundie	N/A	Dynamic, ex- trudate weld	22.5	N/A
Schlegel	HDPE	Schlegel	N/A	Extrusion weld	34	6.0

SOURCE: Telephone interviews and product brochures

TABLE 6 (Continued). STANDARD LINER SEAMS AND WIDTHS

Roll Good Producer	Type	Sheet Fabricators	Seams		Width	
			Factory	Recommended Field	Sheet (ft)	Rolls (ft)
B. F. Goodrich	PVC	B. F. Goodrich	Dielectric, thermal weld	Solvent weld	100	6.0
	PVC-OR	B. F. Goodrich	Dielectric, thermal weld	Solvent weld	100	6.0
	Hypalon	B. F. Goodrich	Dielectric, thermal weld	Solvent weld	100	5.0
	CPE	B. F. Goodrich	Dielectric, thermal weld	Solvent weld	100	6.0
	EPDM	B. F. Goodrich	Dielectric, thermal weld	Solvent weld	100	6.0
Carlisle	EPDM	Carlisle	Vulcanized	Adhesive	50	10.0
		Watersaver	Dielectric, solvent weld	Solvent weld	70	4.5
	Butyl	Carlisle	Vulcanized	Adhesive	50	10.0
Shelter-Rite	Neoprene	Carlisle	Vulcanized	Adhesive	50	10.0
	Ethylene interpolymer alloy	Shelter-Rite	Dielectric, thermal weld	Thermal weld		4.8

SOURCE: Telephone interviews and product brochures

TABLE 7. PRELIMINARY LINER SELECTION

TYPE	ROLL GOOD PRODUCER
PVC	B. F. Goodrich Mainline Pantasote
PVC-OR	B. F. Goodrich Mainline Pantasote
CPE	B. F. Goodrich Mainline Pantasote
Hypalon	Stevens Pantasote B. F. Goodrich
HDPE	Schlegel Gundle
Ethylene interpolymer alloy (XR-5)	Shelter-Rite
EPDM	Carlisle B. F. Goodrich
Neoprene	Carlisle

CHAPTER 3

SELECTION OF TEST METHOD

Even when a polymeric liner has been properly installed, a failure of the liner can result from loss of liner integrity due to weathering or incompatibility of the liner with the chemical components of a waste. The selection of an appropriate liner must therefore focus on the degree to which the candidate liner can maintain its integrity over the projected life of the containment facility. Because liner performance data are limited, selections should be based in part on the results of exposure testing that simulates projected conditions.

An exposure test should be designed ideally as an accurate model of the intended application. The test should yield sufficient data that the results can be projected over the anticipated life of the facility, and the results should be useful for prediction of actual field performance. Unfortunately, because of the large number of variables that can affect liner integrity and the limited field data available on liner performance, no such liner exposure test has been developed. As a result, it is necessary to utilize a test procedure that best reflects a projected exposure condition and long-term liner performance. Moreover, the test procedure should be based upon accepted methods and have sufficient definition and control of test variables for reproducibility of results and comparison with results from other tests.

EXISTING METHODS

Liner Exposure Methods

Liner compatibility testing procedures focus on the method used to expose the liner samples to the test waste. Standard procedures for exposing liner samples to test wastes are only now being developed. As a result, a wide variety of exposure methods and test variables are presently being used. A majority of the liner exposure methods that have been used are adaptations of the American Society for Testing and Materials (ASTM) Method D-471 (Rubber Property Effect of Liquids), and ASTM Method D-543 (Resistance of Plastics to Chemical Reagents). These immersion tests, which are summarized in Table 8, have been used for both initial and long-term evaluation of liner compatibility.

In these immersion tests, specimens of a liner are immersed in the test waste and, after given exposure times, the liner specimens are removed and the changes in weight, dimensions and tensile properties are determined. Most immersion tests use the same immersion procedure; however, the test temperature, duration and evaluation criteria differ.

TABLE 8. EXPOSURE METHODS - IMMERSION TESTS

Reference	Test Temperature	Test Duration	Primary Analysis	Comments
Haxo, Henry (Matrecon)	72°F	To 800 days	Visual, weight change, ultimate elongation, S-100 modulus, volatiles, extractibles	Test method development
National Sanitation Foundation				
- initial evaluation	23°C (72°F) & 50°C (122°F)	1, 3, and 7 days	Weight change, dimensional change, visual	Developed as standard exposure procedure
- long-term evaluation	23°C (72°F) & 50°C (122°F)	1, 7 and 14 days 1, 2 and 4 months	Weight change, dimensional change, tensile strength, S-100 modulus, ultimate elongation, seam strength tear test	
Exxon Chemicals	72°F	1, 3, 6 and 12 months	Visual, weight change, ultimate elongation, S-100 modulus, tensile strength	Used to develop compatibility data
	212°F	72 hours		
Palco Linings, Inc.	72, 122 & 158°F	7, 30, 60 and 90 days	Weight change, ultimate elongation, tensile strength, S-100 modulus	Used weight change for preliminary screening after 14 days exposure
J.P. Stevens Company	72°F & elev. temp	7, 14, 21 and 28 days	Weight change	Seek the equilibrium condition
Dow Chemical	72 & 140°F	7, 14, 30, 60, 90, 120 days	Ultimate elongation, tensile strength, S-100 modulus	

TABLE 8 (Continued). EXPOSURE METHODS - IMMERSION TESTS

Reference	Test Temperature	Test Duration	Primary Analysis	Comments
Carlisle Tire and Rubber Company	72°F & anticipated service	30 days	Tensile strength, ultimate elongation, S-100 modulus	
ASTM D-471 D-543	Dependent on anticipated service temperature	22, 70, 166 and 670 hours	Any/all of weight change, dimensional change, tensile strength, ultimate elongation and hardness	
D-3083	90° & 100°F	30 days	Tensile strength and ultimate elongation	Soil burial test
Schlegel Liners	72° & 158°F	7, 14, 21 and 28 days	Weight change, tensile strength, ultimate elongation	Seeks the equilibrium condition

SOURCES: (1) Haxo, ASTM 1982
 (2) National Sanitation Foundation, Proposed Standards
 (3) Telephone interviews

Except for the test used by Haxo, all the immersion tests are run at both ambient (23°C) and elevated temperatures. The elevated temperature is intended to simulate adverse conditions and to accelerate any deleterious effects that the waste may have on the liner. However, there is no consensus as to what this elevated temperature should be. As a result, the elevated test temperatures vary from 50°C to 100°C for the identified tests. The ASTM methods recommend exposure of materials at higher temperatures if elevated temperatures are expected in service.

Each immersion test uses a different test duration. The exposure period for long-term tests tends to vary from one to four months; however, Haxo and Exxon have used exposure periods of one year or longer. In all cases liner specimens are tested several times during the test so that the effect of the waste on the liner can be determined as a function of time. This procedure allows one to determine if the liner stabilizes after a given length of time.

Finally, there are no consistent criteria for evaluating the test results, specifically with respect to what degree of change is acceptable. For example, Schlegel uses compatibility criteria of no more than 3-percent change in weight and 10-percent change in tensile properties, while J. P. Stevens will allow a change of approximately 20-percent in analysis properties (assuming that the analysis results have stabilized).

In addition to immersion tests, a number of other exposure methods have been developed and used in attempts to more closely simulate actual field conditions. These additional tests are listed in Table 9 and can be characterized as landfill simulation, weathering and permeability tests.

Landfill simulators permit the liner to be exposed to a stratified or solid waste and to a hydraulic head. Landfill simulators have been used by Styron and Fry and by Haxo for long-term, research-oriented studies of one year and roughly three years, respectively. By their nature, landfill simulators do not permit temperature to be controlled and intermediate assessments of replicate systems are expensive.

Weathering tests are used to address what combined effect a waste and climatic variations has on a liner. J. P. Stevens uses a heat lamp on a laboratory scale to simulate the effect of waste stratification and ultra-violet light on a liner. On a larger scale Haxo has used lined outdoor waste tanks and an exposure period of four years to evaluate weathering effects, and DSET Laboratories has developed a patented, ASTM-approved, accelerated weathering test (which does not include exposure to waste).

The only membrane liner waste permeability test reported in the literature was a pouch test used by Haxo. In this test, waste was sealed in a pouch made of a liner specimen and the pouch was immersed in de-ionized water. The flows of ions and water across the liner were then monitored.

TABLE 9. ADDITIONAL EXPOSURE METHODS

Reference	Test	Test Duration	Primary Analysis	Comments
Haxo, Henry (Matrecon)	Simulation cells	To 1,200 days	Weight change, ultimate elongation, S-100 modulus, volatiles, extractibles	Landfill simulators
	Weathering tests	To 1,231 days	Ultimate elongation, S-100 modulus, extractibles	Exposure of membrane to weather
	Tub tests	4 years	Visual	Weathering of waste air interface. Most severely attacked area
	Pouch tests	1,000 days	Weight of liner pouch, pH and conductivity of water	Attempts to compare relative permeabilities
J. P. Stevens Company	Exposure tests, uncovered - sunlamp	7, 14, 21 and 28 days	Visual, weight change	Causes stratification of waste & exposure of waste/air interface
	Exposure test, covered - sunlamp	7, 14, 21 and 28 days	Visual, weight change	Lamp acts as heater
Styron and Fry	Lagoon simulation	12 months	Breaking strength, ultimate elongation	Lagoon simulation, pressurized to create 9 meters of head
DSET Laboratories	EMMAQUA® Test method	Variable	Variable	Accelerated weathering test

SOURCES: (1) Haxo, ASTM 1982
 (2) National Sanitation Foundation Proposed Standards
 (3) Telephone interviews
 (4) Desert Sunshine Exposure Tests, Inc.

Liner Analysis Methods

Liner analysis methods are protocols used to monitor the changes in the liner specimen as a result of exposure to the waste. Analysis procedures involve visual inspections and measurements such as the weight and dimensions, tensile properties, plasticizer content and permeability of the liner specimen. These analyses focus on monitoring the stability of the liner material when exposed to the waste.

Visual analyses are used to provide an initial indication of any degradation of the liner sample that has resulted from exposure to the waste. After exposure the liner is examined for blistering, loss of surface gloss, tackiness, swelling, crazing, bubbling, cracking, softening or decomposition. As a basis for these observations, the definitions in ASTM D-883 (Terms Related to Plastics) are used.

Weight and dimension changes are used to determine the degree of waste absorption by the liner (the uptake of soluble constituents by the liner) or the removal of soluble constituents from the liner by the waste. Waste absorption (weight gain and swelling) by the liner indicates that the liner polymer is soluble in the wastes and leads to a loss of tensile properties and softening of the liner. The removal of soluble constituents (loss of weight and shrinkage) from the liner is indicative of loss of plasticizer from the liner and results in a hardening and embrittlement of the liner (Haxo 1982).

Measurement of the tensile properties of the liner specimen is used as a direct indicator of the effect of the waste on the liner specimen. Such measurements permit the effect of waste absorption, removal of soluble constituents or changes in seam strength to be quantified after exposure. Tests used to monitor these changes include: tensile strength - the stress at failure; ultimate elongation - the elongation at failure; and the S-100 modulus - the stress at 100 percent elongation. In addition to these three tensile tests, the National Sanitation Foundation (NSF), in their proposed testing criteria, suggests that tear strength also be measured.

While the above tests have been used by many researchers, Haxo has also used the volatile loss and extractibles content of the liner to determine the loss of plasticizer from the liner, and has proposed using measurement of membrane permeability as a compatibility test. Volatile loss and extractibles are modified ASTM analyses which provide a means to identify the relative degrees of waste absorption and plasticizer loss, factors which cannot be isolated just by measurement of weight change. Although permeability is assumed not to be a critical parameter in evaluating liners (NSF), Haxo has also proposed using water vapor transmission and gas transmission to measure relative liner permeability.

TEST METHOD EVALUATION

Liner Exposure

Of the identified liner/waste exposure methods, only immersion tests and landfill simulator tests have been used extensively. Although weathering can have a significant effect on long-term liner integrity, its impact is highly site-specific and difficult to simulate. Only the DSET Laboratories test is a fully documented and ASTM approved procedure for measuring the effect of weathering, but it is only applicable to the simulation of weather effects and cannot be used to measure waste effects. Because of the inherent impermeability of polymeric liners, permeability is not considered to be a meaningful evaluation criteria (NSF). Additionally, no direct permeability test procedure is available. There are insufficient data on the pouch test developed by Haxo to define what is measured by this procedure or its significance. Even though landfill simulators are designed so that leachate can be collected, permeability data from landfill simulators have yet to be published.

Immersion Tests

Immersion testing is the only widely-used procedure for determining the compatibility of polymeric liners with a test waste solution. This procedure evolved from standard ASTM test procedures for determining the compatibility of plastics and rubber with chemicals. A standard test protocol for liner compatibility with wastes has been recently proposed by the NSF. In addition to wide acceptance, the key advantages of immersion tests are the ability to fully define test parameters, limited exposure time and conclusive results. The key disadvantages are field conditions cannot be fully simulated and solid or semi-solid wastes are difficult to test.

Because liner samples are exposed by immersing them in a test solution containing the waste, the area, equipment and waste quantity needed for immersion tests are small. As a result, it is feasible to expose multiple samples of a liner to a large number of variables such as waste concentration, exposure time, waste temperature and seam type.

Although exposure times of up to one year have been used for immersion tests, periods of one to four months are commonly used because any loss in liner integrity resulting from chemical attack generally occurs within a short exposure time. Based on the compatibility data published by Exxon, the loss of integrity typically occurs within a month with concentrated chemicals. Additionally, accelerated exposure testing by increasing the temperature of the waste is used in both the initial ASTM procedures and in the proposed NSF test protocol.

Immersion tests, although widely used, have not been useful for simulation of actual field conditions. In particular, the interface between the waste and atmosphere cannot be duplicated and the effect of waste concentration gradients on the liner cannot be investigated. As a result, some concern has been raised as to the degree that immersion test results can be projected to actual use. A second key disadvantage of immersion testing is the difficulty of using solid or semi-solid waste. Procedures for conducting immersion tests with solids or semi-solids have not been standardized and it is unclear how well the test procedure can be adapted to solids; however, there is an ASTM procedure for soil burial of liners and a similar procedure has been used by Haxo in his research.

Landfill Simulator Tests

Landfill simulation tests attempt to simulate more closely actual field conditions and, as a result, to reflect more closely the actual effect of a waste on a liner. To date only a limited number of landfill simulator tests have been performed and a standardized or widely accepted landfill simulator procedure has not been developed. The key advantages of landfill simulator tests are the capabilities to simulate more closely field conditions and to use waste in a solid or semi-solid state. The disadvantages are that these units lack flexibility, are expensive and the validity of the results has not been demonstrated.

Unlike immersion tests where the liner specimens are simply suspended in a test waste solution, the liner specimen serves as the base of a simulated landfill in a landfill simulator. Factors such as exposure of the liner to a waste concentration gradient, a hydraulic head, and single side exposure can be simulated. It is assumed that such test results will more accurately reflect the interactions between the waste and the liner that occur in actual use and, thus, result in better predictions of long-term liner performance.

Because landfill simulators are constructed as tanks or columns with the liner specimen located at the base, the liner can be exposed to a solid waste without any special modification of the test procedure. Thus, test results from solids exposure should be comparable directly to liquid exposure results.

Although landfill simulators may better simulate actual field conditions, the volumes of material and waste required are large. Thus, fewer data points can be obtained and test variables are more difficult to control. Because each liner specimen must be installed in an individual test cell, a large number of test cells and large volumes of waste are required for a large scale test. As a result, fewer duplicate samples can be run and fewer variables investigated. Because only one side of the liner is exposed to the waste, longer exposure periods are required. In previous tests, exposure periods have been one year or greater. As a result, much less test data can be obtained within a given time and budget.

Of greater concern is the significance of the test results. Landfill simulators are still only an approximate model of actual service conditions. No standardized procedure has been developed and, until more field data are available, it will not be known how well landfill simulators actually reflect field conditions. Additionally, because of their size and long exposure times, it is difficult to closely control individual test variables during the test and, as indicated, fewer samples and variables can be run.

Liner Analysis

Unlike exposure methods where a number of alternative procedures have been used, most researchers have used the same ASTM analysis procedures in measuring the effect of waste exposure on liner integrity. The major difference between researchers is the number of analyses performed. However, there is no agreement on how the results relate to liner performance in the field. All the ASTM test procedures contain the qualification that results are relative and expected performance should also be based on past experience. As a result, interpretation of results vary; specifically, the degree of change that can be tolerated from the original physical properties of the liner material.

RECOMMENDED TEST PROCEDURES

The proposed NSF Test Protocol (Appendix B) was selected for the liner compatibility testing with explosives and solvents. The NSF test has been proposed by the National Sanitation Foundation Joint Committee in their Draft Final Standards for Flexible Membrane Liners. The committee is composed of representatives of manufacturers, regulatory agencies, and users of liners. The standards represent a compilation of the views and ideas of many of the leading authorities on liners.

Immersion tests are the most widely used exposure method for liner compatibility studies and the only exposure method for which there is a standard procedure based on ASTM test methods. Immersion tests permit a large number of data points to be compiled, require a limited exposure period and permit close control over test conditions. The major drawback of immersion tests for the planned testing is the lack of past experience with the use of solid waste rather than a liquid waste; however, it would appear that immersion testing with solid waste would be feasible.

The use of landfill simulator tests was rejected because of high cost, limited data yield and limited past use. While landfill simulator tests appear to better simulate field conditions, their predictive ability has not been verified. At this point, landfill simulator tests appear more appropriate to research studies than to compatibility testing.

Liner analysis methods should follow past experience and address visual and physical changes and changes in the structural properties of the liner. Although not generally performed in the past, the testing should also address seam strength.

CHAPTER 4

PROCEDURES

The NSF screening test was conducted using samples of 12 synthetic membrane liners in solutions containing TNT, RDX and TCE. The experimental design, equipment, test procedures, data collection and reduction and critical observations on the test protocol are presented in this chapter.

EXPERIMENTAL DESIGN

The exposure test matrix used for each of the 12 liner materials is presented in Table 10. A listing of the 12 liners is given in Table 11. Five test environments were evaluated at either one or two temperatures (23°C and 50°C). These test environments included air (unexposed) and distilled water controls as well as the TNT, RDX and TCE test solutions. TNT and RDX were evaluated only at 50°C due to their relative insolubility at 23°C. Water saturated TCE, however, was evaluated only at 23°C because of its volatility. The test matrix contained 11 combinations of environment and temperature for each of the 12 liners, or a total of 132 elements. As further described below, each element of the matrix consisted of an immersion jar containing three replicate samples. Weight and volume measurements were made and the visual appearance recorded for each replicate prior to exposure after one, three and seven days of exposure and after seven days of air drying subsequent to the exposure. Thus, weight, volume and appearance were recorded on five occasions over a 14-day test period for each of three replicates in the 132 immersions used in the experiment.

EQUIPMENT

Samples

Each of the roll good producers was asked to provide 30-mil (0.030-in) samples cut to a 1-inch by 3-inch size for the test program. All manufacturers, except Schlegel, accommodated this request. Schlegel provided HDPE samples in a 60-mil (0.060-inch) thickness, the minimum that it manufactures. The pre-cut samples received from some of the manufacturers were not uniform and required trimming before use. Subsequent submissions of sample materials were requested in an uncut form. Test samples were stamped out with a 1-inch by 3-inch precision ASTM die.

TABLE 10. EXPERIMENTAL CONDITIONS FOR SCREENING TESTS

No.	Environment	Temperature	Test Solution
1.	Air blank	23°C	Unexposed
2.	Air blank	50°C	Unexposed
3.	Water blank	23°C	Distilled water
4.	Water blank	50°C	Distilled water
5.	TNT	50°C	TNT-saturated water
6.	RDX	50°C	RDX-saturated water
7.	TCE	23°C	100 mg/l aqueous solution
8.	TCE	23°C	TCE-saturated water
9.	TCE	23°C	Water-saturated TCE
10.	TCE	50°C	100 mg/l aqueous solution
11.	TCE	50°C	TCE-saturated water

TABLE 11. LINERS USED FOR INITIAL EXPOSURE TESTING

<u>TYPE</u>	<u>ROLL GOOD PRODUCER</u>
PVC	Mainline (Palco) ¹ Pantasote
PVC-OR	Mainline (Palco) ¹ Pantasote
CPE	Mainline (Palco) ¹ Pantasote
Hypalon	Stevens Pantasote
HDPE	Schlegel
Ethylene Inter- polymer Alloy	Shelter-Rite
EPDM	Carlisle
Neoprene	Carlisle

¹ Mainline supplies roll goods exclusively to Palco, a sheet fabricator. Palco was the supplier of test samples and are the listed manufacturer in the remainder of this report.

Immersion Jars

Wide mouth one-quart jars were used for immersing the samples at 23°C and 50°C. The immersion jar is shown in Figure 1. Three replicate 1-inch by 3-inch liner samples were suspended in each jar. These containers nominally provided 55 ml of solution per square inch of material; the NSF test procedure requires a minimum of 40 ml of solution per square inch. The shape of the quart jars proved to be well suited because the wide mouth permitted easy insertion and removal of the strips and its size allowed the samples to be suspended freely. Also, the jars were easily sealed with standard lids. The lids, with separate inserts and rims, further simplified suspending the samples.

The liner samples were suspended in the immersion jars with 22-gauge nickel-chromium wire and were labeled with numbered aluminum tags. The nickel-chromium wires and the tag attached to each sample weighed 0.373 ± 0.05 gm. The samples were weighted initially with zinc-coated carbon steel nuts (7 ± 0.2 gm). These nuts were later replaced with stainless steel nuts of the same weight.

Reagents

The candidate liner samples were immersed in solutions of TCE, TNT and RDX. The TCE was Curtis Matheson Scientific, Inc. purified grade; the TNT, Eastman Kodak, practical grade; and the RDX supplied by USATHAMA was Type II Class A production run.

Equipment

Volume measurements were made using calipers (Mitutoyo No. 505-625) for length and width and a spring-loaded dial bench gauge (Starrett No. 25-131) for thickness. Weight measurements were made with a Mettler H10 balance.

The 50°C tests were performed in a Blue M Electric Company "Power Matic 60" oven. The oven was maintained at a constant $50^\circ\text{C} \pm 2^\circ\text{C}$ throughout the immersion period. Samples were cut with a 1-inch x 3 inch precision die (manufactured to ASTM specifications) produced by Custom Scientific Instruments, Inc.

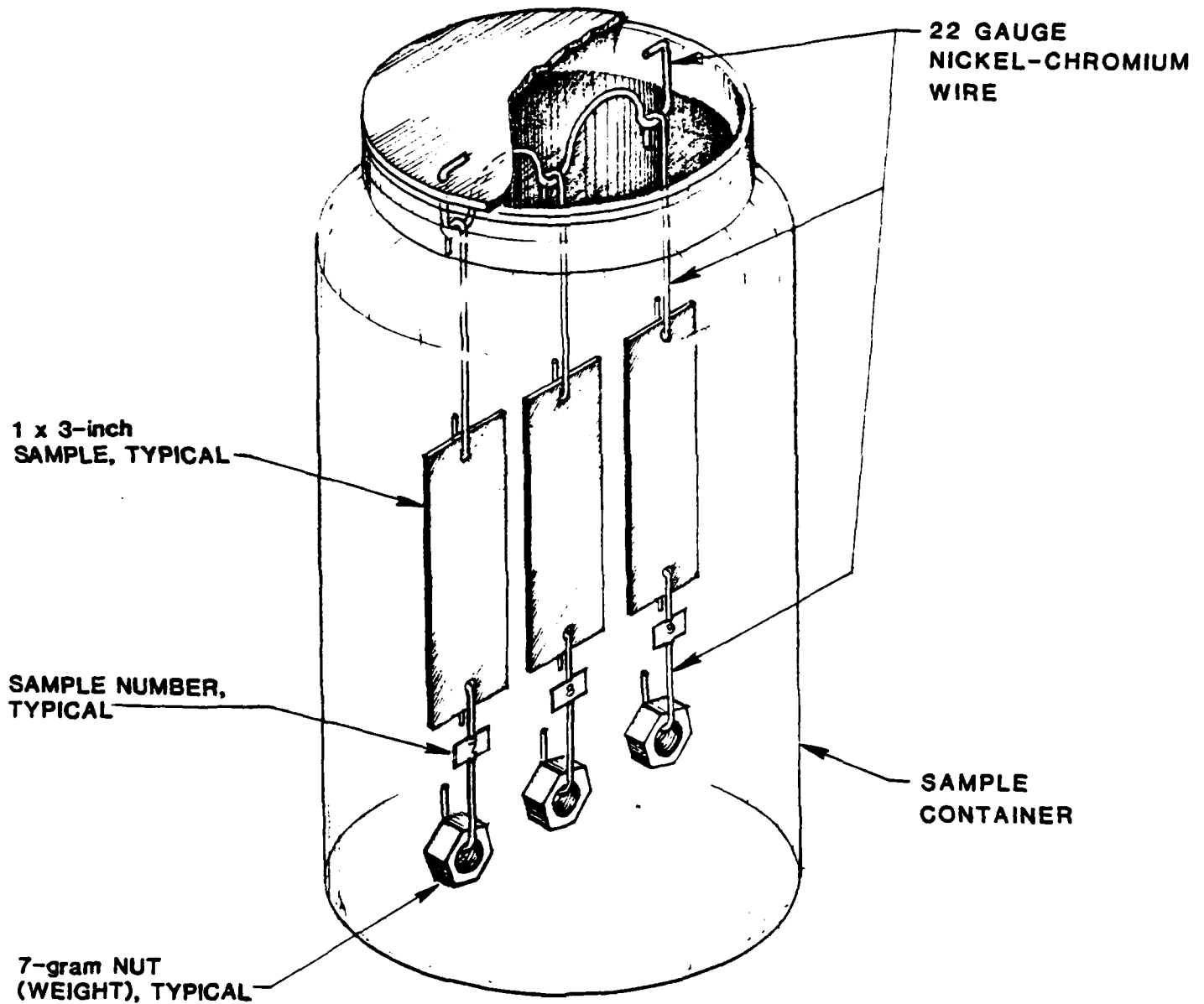
PROCEDURES

Setup

The three replicate samples in each jar were suspended from the lid with hooks made of 22-gauge nickel-chromium wire. A hanger with three loops was made with this same material and was attached to each lid. The liner samples were hooked to the hanger as shown in Figure 1. The samples were weighed and measured both initially and during testing with the hooks in place. To prevent curl and contact with the other

FIGURE 1

TYPICAL LINER SAMPLE IMMERSION JAR



strips, each sample was weighted with a nut using a second hook. The nut was removed from the bottom hook for weighing and measuring. Initially, zinc-coated steel nuts were used. These corroded severely during the elevated temperature immersions and were replaced with stainless steel nuts.

The three replicate samples in each immersion jar were handled together throughout the 14-day test period (seven days of immersion followed by seven days of air drying). The jars were labeled so as to identify the liner type, solution and jar number. Individual samples were labeled with a numbered aluminum tag attached to the bottom nickel-chromium hook. The tag number was used as identification on the data sheets.

Solutions

The test solutions were as follows:

- (1) Unexposed - control, exposed only to the atmosphere
- (2) Water Blank - distilled water control
- (3) TCE-saturated water - distilled water and TCE were mixed in a separatory funnel. The excess TCE was drained and the water saturated with TCE drained into the immersion jars. Excess TCE was then poured into each jar (TCE has a density of 1.46 gm/cc and thus remained at the bottom of the jar) to maintain saturation conditions. The excess was checked daily and additional TCE added if necessary.
- (4) Water-saturated TCE - TCE and distilled water were mixed in a separatory funnel. The TCE was then drained into the immersion jars. Excess water was added to each jar forming an aqueous layer above the highest point of the liner strips. The water layer over the water-saturated TCE served to minimize the release of TCE vapor.
- (5) TCE, 100 mg/l aqueous solution - This solution was prepared by adding 56 microliters of TCE to 800 ml of water in the immersion jar. The solution was mixed before adding the samples.
- (6) TNT-saturated water - TNT-saturated water was prepared by adding TNT crystals in excess of the solubility limit to distilled water. The presence of TNT crystals was checked daily and additional crystals were added if necessary. At 50°C, the saturation concentration of TNT in aqueous solution is approximately 450 mg/l.
- (7) RDX-saturated water - RDX-saturated water was prepared by

adding RDX crystals in excess of the solubility limit to distilled water. The presence of RDX crystals was checked daily and additional crystals added if necessary. At 50°C, the saturation concentration of RDX in aqueous solution is approximately 450 mg/l.

Immersion Procedure

The samples were exposed to air at room temperature prior to start of the experiments. Initial weight and volume measurements were made no more than four hours before immersion in accordance with the NSF proposed method. All three replicate samples were removed from the jars at the same time for measurement. The samples were then individually blotted, dipped in acetone and wiped dry prior to weighing. During the drying and weighing, the samples were handled with forceps. The weighing was conducted as rapidly as possible to avoid the loss of volatile components from the liner.

After weighing, the length of the samples was measured at two points and the width and thickness at three. During the length and width measurements the sample was held flat on a desk surface and care was taken to avoid flexing the sample. The samples were then returned to the test solutions.

The rims of the lids of the immersion jars tested at 23°C were tightened snug. The rims of the cells containing TCE in 100 mg/l solutions at 50°C were left loose, and no rims were used in the experiments with the other solutions at 50°C. This procedure was used to preclude the buildup of pressure in the cells, a precaution that proved to be unnecessary and is not recommended for future tests. After the 7-day exposure period, each immersion jar was emptied and dried. The liner samples were then resuspended in the same jars with weights replaced for the air drying period. The lids were removed for the 7-day air drying period.

DATA COLLECTION/REDUCTION

The forms used for data collection and reduction are presented in Appendix E. The jar number and the start date were used to identify the data sheets. Each sample was tracked by its individual sample number from the aluminum tag. Raw data were recorded on the Data Sheet (E-1).

The dimension measurements were averaged and entered with the weights on the Data Summary Sheet (E-2). The volume of each sample was calculated using averaged measurements for each dimension and then entered on the data summary sheet.

The results of the data reduction are contained on the Test Result Sheets (E-3). Three critical parameters were defined for assessing liner compatibility. They were:

- o Weight change during immersion - the difference between initial sample weight and sample weight just after removal from the immersion jar following 1, 3, and 7 days of immersion; indicative of what would happen to a liner under continuous exposure to a test solution.
- o Dried weight change - the difference between initial sample weight and sample weight after the 7-day drying period; a measure of the loss of liner components or gain of insoluble chemicals in the waste.
- o Absorbance - the difference between the 7-day immersed weight and the weight after the 7-day drying period; a measure of the tendency of the liner to take up fluid during the immersion cycle which also takes into account the parallel loss of components.

Two additional parameters were calculated based upon volume changes and were reported on the Test Result Sheet (E-3). These parameters were volume change during immersion and swell. The volume change during immersion is the difference between initial sample volume and the sample volume after 1, 3, and 7 days of immersion. The swell is the difference between the 7-day immersed volume and the volume after the 7 day drying period. As the volume parameters did not yield the same consistent pattern of results that was obtained from the weight and absorbance parameters, the volume parameters were computed but not used in subsequent interpretations.

The weight and volume changes during immersion were calculated as follows:

$$\% \text{ weight change} = \frac{(W_t - W_o) \times 100}{W_o} \quad (1)$$

where: W_t = weight (gm) after exposure time for immersion times of 1, 3 and 7 days and for the final weight change after the subsequent 7 days of air drying.

W_o = initial weight (gm)

$$\% \text{ volume change} = \frac{(V_t - V_o) \times 100}{V_o} \quad (2)$$

where: V_t = volume (cubic inches) after exposure time for immersion times of 1, 3 and 7 days and for the final volume after the subsequent 7 days of air drying.

V_o = initial volume (cubic inches)

The dried weight change, absorbance and swell were calculated as follows:

$$\% \text{ dried weight change} = \frac{(W_d - W_o) \times 100}{W_o} \quad (3)$$

where: W_d = weight (gm) after 7 days of drying

W_o = initial weight (gm)

$$\% \text{ absorbance} = \frac{(W_7 - W_d) \times 100}{W_o} \quad (4)$$

where: W_7 = weight (gm) after 7 days of immersion

W_d = weight (gm) after 7 days of air drying

W_o = initial weight (gm)

$$\% \text{ swell} = \frac{V_7 - V_o}{V_o} \times 100 \quad (5)$$

where: V_7 = volume (cubic inches) after 7 days of immersion

V_d = volume (cubic inches) after 7 days of air drying

V_o = initial volume (cubic inches)

OBSERVATIONS ON PROCEDURE

The proposed NSF liner compatibility test procedure was straightforward and no major problems were encountered during the testing period. The procedure permitted the screening of the 132 combinations of liners and test environments with good reproducibility of test results. Specific observations on the procedures used are presented below.

Equipment

The physical setup used to immerse the liner samples worked well and presented few problems. The immersion jars were easy to handle and allowed easy removal and replacement of test samples. The suspension system with support wires permanently attached to the liner samples allowed easy and rapid removal of the samples for measurement and minimized handling during the measurement procedure. Moreover, the tag affixed to the support wire of each liner provided a permanent sample identification.

The initial measurements for the liner samples are presented in Table 12. The weight of the support wires and tag attached to each sample is included in all the weighings. These components average 0.373 gm in weight or approximately 10 percent of the initial weights of the samples.

The zinc-coated carbon steel nuts that were used as weights worked well for the immersions conducted at 23°C but corroded severely in the immersions conducted at 50°C. This problem was corrected by replacing these nuts with stainless steel nuts. There was an initial concern that the weights would elongate the samples; however, no elongation was noted. The weights did enlarge and tear through the hook hole in those liners that were softened by immersion in the water-saturated TCE solution. Since these samples subsequently disintegrated, the effect of the weight was not viewed as significant.

TABLE 12. SUMMARY OF INITIAL (PRE-IMMERSION) SPECIMEN WEIGHT AND VOLUME

Liner Material	Specimen Weight		Specimen Volume	
	Mean (gm)	Standard Deviation (gm)	Mean (in. ³)	Standard Deviation (in. ³)
PVC (Palco)	2.313	0.034	0.0847	0.002
PVC (Pantasote)	2.270	0.036	0.046	0.002
PVC-OR (Palco)	2.267	0.064	0.0815	0.0029
PVC-OR (Pantasote)	2.444	0.035	0.0857	0.0021
CPE (Palco)	2.539	0.039	0.0913	0.0020
CPE (Pantasote)	2.427	0.028	0.0839	0.0011
Hypalon (Stevens)	2.442	0.043	0.0816	0.0015
Hypalon (Pantasote)	2.557	0.053	0.0874	0.0027
HDPE (Schlegel)	3.524	0.126	0.2055	0.0080
XR-5 (Shelter-Rite)	2.517	0.113	0.0979	0.0057
EPDM (Carlisle)	2.268	0.107	0.0834	0.0048
Neoprene (Carlisle)	2.736	0.111	0.0863	0.0042

The test runs at 50°C were initially conducted without the lid rims on the jars, whereas the rims were attached loosely in subsequent runs. The rims were left off or loose to prevent a build-up of pressure in the jar; however, this precaution proved unnecessary and, in some cases, allowed excessive evaporation of the test solution. As a result, the solution level in three of the jars dropped below the top of the samples. These three jars required retesting.

Solutions

Saturated solutions were used for all but one of the immersion environments in order to maintain a constant chemical concentration. The only unsaturated solution (an aqueous solution of 100 mg/l TCE) proved extremely difficult to control and impossible to maintain at a constant concentration. The TCE concentration would drop to approximately 50 to 60 mg/l after a 1-day period requiring the addition of TCE daily to return the TCE concentration to the 100 mg/l range. The cause of the loss of TCE was assumed to be a combination of absorption into the liner, adsorption onto the surfaces of the immersion jar, and volatilization; exact cause was not determined.

The concentration of TCE in the TCE-saturated water solutions was found to be less than projected. While the maximum solubility of TCE in water is approximately 1,000 mg/l at 23°C, analysis of the test solutions indicated that the actual TCE concentrations attained were 500 ± 50 mg/l in both the 23°C and 50°C solutions. Also, at 50°C the liners tended to swell to a greater degree at the bottom than at the top. Based on this visual observation it was inferred that a concentration gradient was established with higher concentrations near the bottom.

Weight Measurements

The most precise parameter used was weight change; however, it was not possible to obtain the precision implied in the NSF procedure for all liner/chemical combinations. The NSF procedure does not state a weighing precision but it does specify the use of a balance with a 1-mg precision. The data for the test is reported to three decimal points 0.001 gm (1 mg); however, in some cases, the third decimal point was an estimate. The liner samples immersed in water-saturated TCE would lose weight while on the balance pan; thus it was not possible to obtain a steady weight to the third decimal point. This effect was also noted (to a much lesser degree) with the other samples.

In reference to the acetone rinse, the samples were carefully and quickly wiped dry. Even with this procedure it is suspected that the liner materials absorbed acetone and then released it during weighing. The weight of the sample on the pan would decrease with

time even for those samples left unexposed (i.e., in air). Also, an acetone odor was detected in the immersion jars of the unexposed (control) samples. The effect of acetone absorption was minimized by using the acetone dip step for all weighings including the initial (tare) and final weighings.

Because of the changing weight, any variation in the time delay between drying and weighing would cause inconsistent weight readings. The NSF method calls for immediate weight readings because of this condition, and a standard procedure (as standard as possible) was used. Nonetheless, because it is impossible to reproduce exactly the drying-weighing procedure each time, the weights may deviate because of procedure as opposed to chemical effect. Even with the preceding considerations, the relative impact of weight changes during measurement was not significant.

Volume Measurements

Volume measurement was less precise than weight measurement because the method of measurement was not wholly satisfactory. The NSF proposed procedure specifies a dimensional measurement accuracy of 0.001 inches using a micrometer. A micrometer (caliper) is not suited for measurement of flexible material, especially to an accuracy of 0.001 inches. To measure length and width, the samples were held flat and every effort was made to not squeeze (and thus flex) the material; however, it was impossible to completely avoid flexing the liner sample. Also, the potential for flexing the samples increased after they softened in the water-saturated TCE solution. A second possible measurement error with the micrometer was not having it aligned perpendicular to the sample, thus altering the measurement.

The compression of the samples while measuring thickness was minimized by using a spring-loaded dial bench gauge. The spring delivers the same amount of pressure during each measurement. For those samples that softened during the exposure period, additional compression was evident during the measurement. The measurement of thickness also became very difficult if ply separation occurred; it was difficult to determine if the thickness of the sample had actually increased or if the increase was caused by the ply separation.

The pre-cut samples provided by the manufacturers were often not exact 1-inch x 3-inch rectangles. The non-uniform rectangles made accurate measurement difficult even with the two length and three width readings. This problem was eliminated by obtaining material in sheet form from the roll good manufacturers and stamping out samples with a precision ASTM die.

CHAPTER 5

RESULTS

The data base developed in the liner compatibility testing was analyzed to define the weight and volume change parameters as discussed in Chapter 4. The results of the data analysis of the weight change data are presented in Appendices C and D, and the development and discussion of the weight change results are presented in this chapter.

ORGANIZATION OF DATA BASE

The data base contained weight, volume and visual appearance information for the 132 immersions, each with three replicate samples. In order to organize the data base for reduction and analysis purposes, the tested liners were categorized in terms of similarity of composition, and the resulting liner groupings were confirmed based on similar response of the liners within each group to the test solutions.

For each of the 132 immersions, the weight data (weight change after 1, 3, and 7 days of immersion, dried weight change, and absorbance) were averaged and the standard deviations calculated. In spite of the weighing problems noted in Chapter 4, data precision was good for all of the control and aqueous test solutions. The standard deviations of the weight change and absorbance values were no greater than one percent. The water saturated TCE mean values were less precise with standard deviations of up to 10 percent for some liners. However, based on the volatilization of TCE during weighing noted in Chapter 4 and the large weight changes and absorbances that were measured, measurement errors of this magnitude were viewed as not unreasonable.

Once the mean weight change and absorbance values for each immersion had been calculated, the data were grouped to facilitate analysis. For each group the mean and pooled standard deviation were calculated with the pooled standard deviation being used to confirm the validity of the assumed groups. Based on the calculated standard deviations of the individual immersions, an allowable pooled standard deviation of no more than two percent for the control and aqueous test solutions and no more than 15 percent for the water-saturated TCE solutions was established for confirmation of the initially assumed groupings. Where the pooled standard deviation of the initial group exceeded these criteria, subgroups were established that did meet these criteria.

Five basic groups of liners resulted from this categorization of the data. These were PVC/PVC-OR, CPE/Hypalon, HDPE, XR-5 and EPDM/Neoprene. For the CPE/Hypalon group, CPE and Hypalon subgroups were established because of varying response to the test

solutions of the CPE and Hypalon liners. The different groups used for the data analysis are presented in Table 13. The results presented in this chapter are compiled for all liners within each group.

Three quantitative analysis parameters are used to present the weight change results. They are: the percent weight changes during immersion; the percent weight change after the 7-day drying period; and the percent absorbance. These weight change parameters were computed as defined in equations 1 and 3 in Chapter 4, i.e., with reference to the initial sample condition.

The volume data from the 132 immersions were also evaluated using the same procedure; however, the precision of the results for the individual immersions was low with calculated standard deviations equaling or exceeding the measured changes for many of the immersions. As a result the volume change results have not been interpreted.

VISUAL OBSERVATIONS

The visual results for the 12 liners in the five solutions are summarized in Table 14. Visual observations were made during each measurement at 1, 3, and 7 days of immersion and then after the subsequent 7-day drying period. The results are presented below.

TCE-Saturated Water (23°C and 50°C)

There was little visual change in any of the liner samples immersed in solutions of TCE-saturated water at 23°C and at 50°C. The CPE (Pantasote) and Hypalon (Stevens) samples did swell at the bottom. Excess TCE was placed in these jars and accumulated as a lower phase. The swelling was probably due to a concentration gradient formed in the TCE-saturated water phase.

No visual change was noted for immersions in solutions of 100 mg/l TCE at either temperature.

Water-Saturated TCE (23°C)

The liner samples immersed in water saturated TCE (near pure TCE) showed drastic visual change. All of the liner samples (including the HDPE) swelled noticeably and softened, with an apparent loss in structural strength. The samples of three of the liners - CPE (Pantasote), Hypalon (Stevens) and Hypalon (Pantasote) - dissolved to a jelly-like mass within 24 hours. Ply separation was evident on the samples of three of the other liners; PVC (Palco), PVC-OR (Palco), and CPE (Palco). The HDPE samples showed the least visual change; however, the HDPE liner did swell and become much more flexible during the immersion period and an orange tint was imparted to the solution.

TABLE 13. LINER GROUPINGS FOR DATA ANALYSIS

Group	Liners
PVC	PVC (Palco) PVC (Pantasote) PVC-OR (Palco) PVC-OR (Pantasote)
CPE/Hypalon	
CPE Subgroup	CPE (Palco) CPE (Pantasote)
Hypalon Subgroup	Hypalon (Stevens) Hypalon (Pantasote)
HDPE	HDPE (Schlegel)
XR-5	XR-5 (Shelter-Rite)
EPDM/Neoprene	EPDM (Carlisle) Neoprene (Carlisle)

TABLE 14. VISUAL OBSERVATION OF LINER SAMPLES IMMERSED IN TEST SOLUTIONS

LINER	IMMERSION SOLUTION				
	TCE-Saturated Water, 23°C	TCE-Saturated Water, 50°C	Water-Saturated TCE, 23°C	TNT-Saturated Water 50°C	RDX-Saturated Water, 50°C
PVC (Palco)	No observed change	No observed change	Blistered; ply separation Shrank, stiffened and curled after drying	No observed change	Slightly softened and curled
PVC (Pantasote)	No observed change	No observed change	Solution cloudy. Shrank and stiffened after drying.	No observed change	Slightly softened and curled
⁵ PVC-OR (Palco)	No observed change	No observed change	Ply separation, stiffened and curled after drying	Turned slightly yellow	Slightly softened
PVC-OR (Pantasote)	No observed change	No observed change	Solution cloudy, shrank stiffened and slightly curled after drying	Developed small white spots	No observed change
CPE (Palco)	No observed change	No observed change	Solution bright orange. ply separation and blisters. Shrank and stiffened after drying	No observed change	Slightly softened
CPE (Pantasote)	Noticeable swelling at bottom; softer	Noticeable swelling at bottom	Dissolved to jelly-like mass.	No observed change	Slightly softened

TABLE 14. VISUAL OBSERVATION OF LINER SAMPLES IMMERSSED IN TEST SOLUTIONS (Continued)

LINER	IMMERSION SOLUTION				
	TCE-Saturated Water, 23°C	TCE-Saturated Water, 50°C	Water-Saturated TCE, 23°C	TNT-Saturated Water, 50°C	RDX-Saturated Water, 50°C
Hypalon (Stevens)	No observed change	No observed change	Dissolved to a jelly- like mass.	No observed change	Tacky
Hypalon (Pantasote)	No observed change	Noticeable swelling and softening at bottom.	Dissolved to a jelly- like mass.	No observed change	Tacky
HDPE (Schlegel)	No observed change	No observed change	Solution turned bright pink. Slight swelling, softened, more flexible.	No observed change	No observed change
XR-5 (Shelter- Rite)	No observed change	No observed change	Swelled noticeably, sof- tened, blistered and crazed. Shrank, stif- fened and curled after drying.	No observed change	Tacky
EPDM (Carlisle)	No observed change	Noticeable swelling at bottom.	Solution had a green tint. Swelled notice- ably. Shrank and stif- fened upon drying.	No observed change	No observed change
Neoprene (Carlisle)	No observed change	No observed change	Solution had an orange tint. Swelled notice- ably.	No observed change	No observed change

After drying, the liner samples (excluding the ones that dissolved and the HDPE and Neoprene samples) had stiffened and hardened. This change is believed to have been due to a loss of plasticizers. The HDPE and Neoprene samples showed little change, i.e., had not stiffened or hardened after the drying period.

TNT-Saturated Water (50°C)

There was little visual change in the liner samples immersed in the TNT-saturated water solution at 50°C. The PVC-OR (Palco) sample had a slight color change and the PVC-OR (Pantasote) samples developed white spots.

RDX-Saturated Water (50°C)

Slight visual changes were noted for some of the liners immersed in the RDX solutions. Liners in the PVC group softened slightly and curled. The two CPE liners also softened slightly. The other changes noted were that the surfaces of the Hypalon (both Stevens and Pantasote) and the XR-5 samples became tacky after being immersed for 72 hours.

WEIGHT CHANGES DURING IMMERSION

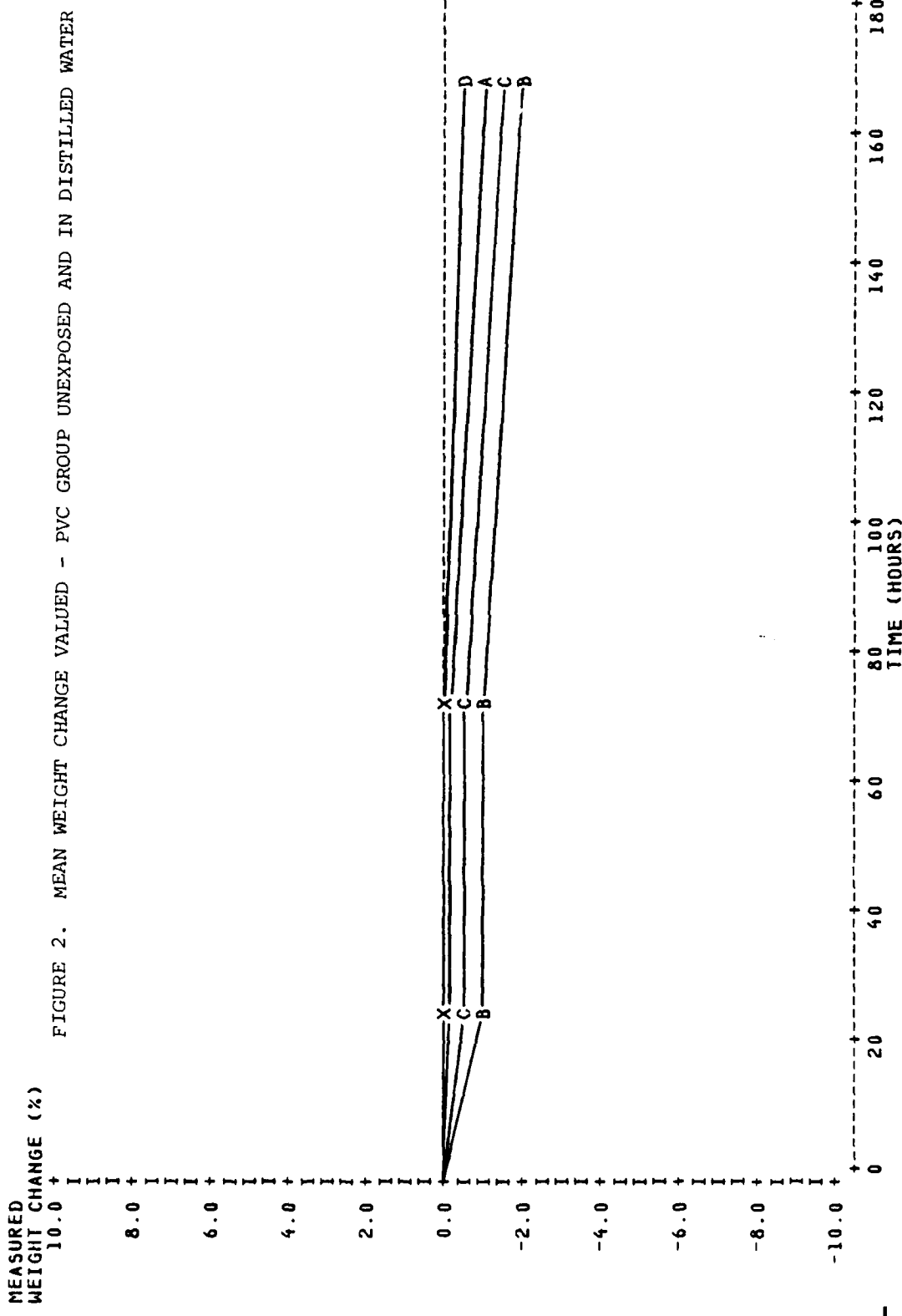
Weight change during immersion pertains to the difference between initial sample weight and its weight just after removal from the immersion jar. This measure, calculated using Equation 1 in Chapter 4, is indicative of what happens to a liner under continuous exposure to a test solution. The weight changes during immersion are presented graphically in Figures 2 through 25. The liner groups are indicated on each plot by letters. Overlapping points, and points that lie on the axis, are indicated by an "X".

Controls

Air (unexposed) and distilled water control immersions were conducted for each liner material. The weight changes for unexposed (un-immersed) liner samples and for the distilled water immersions at 23°C and 50°C are presented in Figures 2 through 6 for the five liner groups: PVC/PVC-OR; EPDM/Neoprene; CPE/Hypalon; HDPE and XR-5. At 23°C there was limited weight change during the 7 day immersion period (less than two percent) for both the unexposed samples and distilled water immersion. At 50°C there was also limited weight change for all the unexposed samples; however, in distilled water both the EPDM/Neoprene samples and the CPE samples had weight increases of approximately four percent by the end of the 7-day immersion period. The remaining liner samples (PVC/PVC-OR, Hypalon, HDPE and XR-5) had limited weight changes (less than two percent) in distilled water at 50°C.

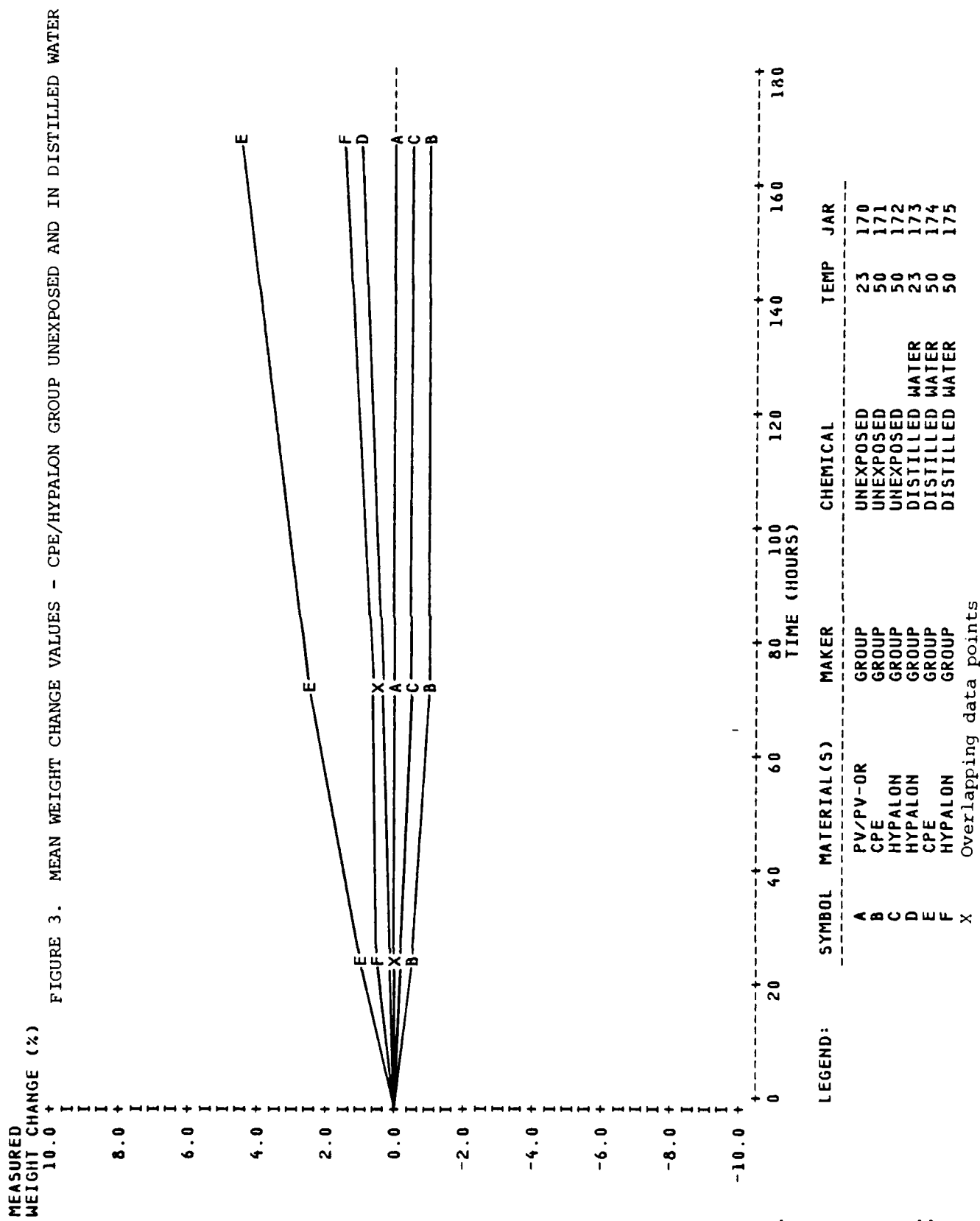
TCE-Saturated Water

The weight changes for the distilled water and TCE-saturated water immersions at 23°C and 50°C are presented in Figures 7 through 11.



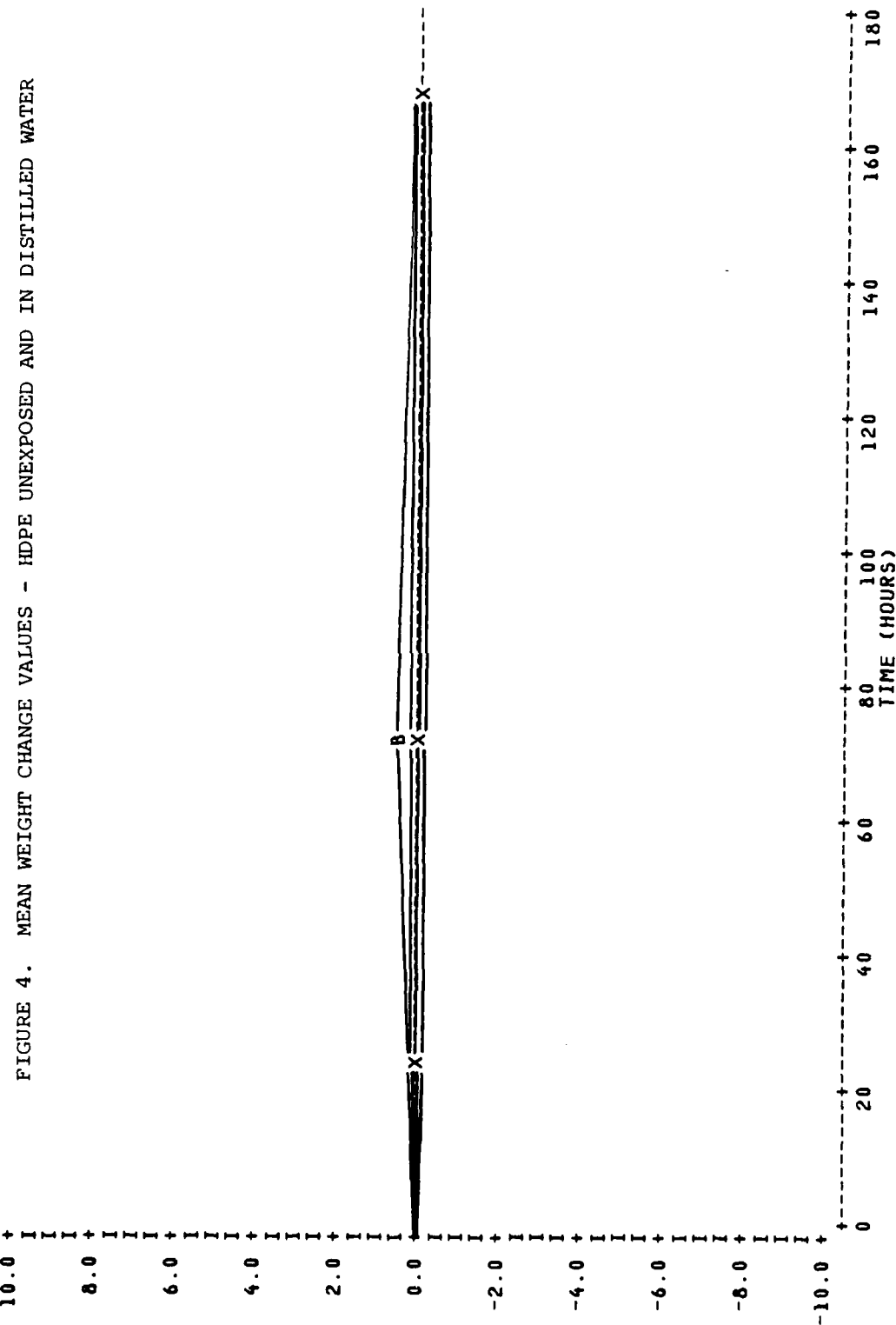
LEGEND:

SYMBOL	MATERIAL(S)	MAKER	CHEMICAL	TEMP	JAR
A	PV/PV-OR	GROUP	UNEXPOSED	23	150
B	PV/PV-OR	GROUP	UNEXPOSED	50	151
C	PV/PV-OR	GROUP	DISTILLED WATER	23	152
D	PV/PV-OR	GROUP	DISTILLED WATER	50	153
X	Overlapping data points				



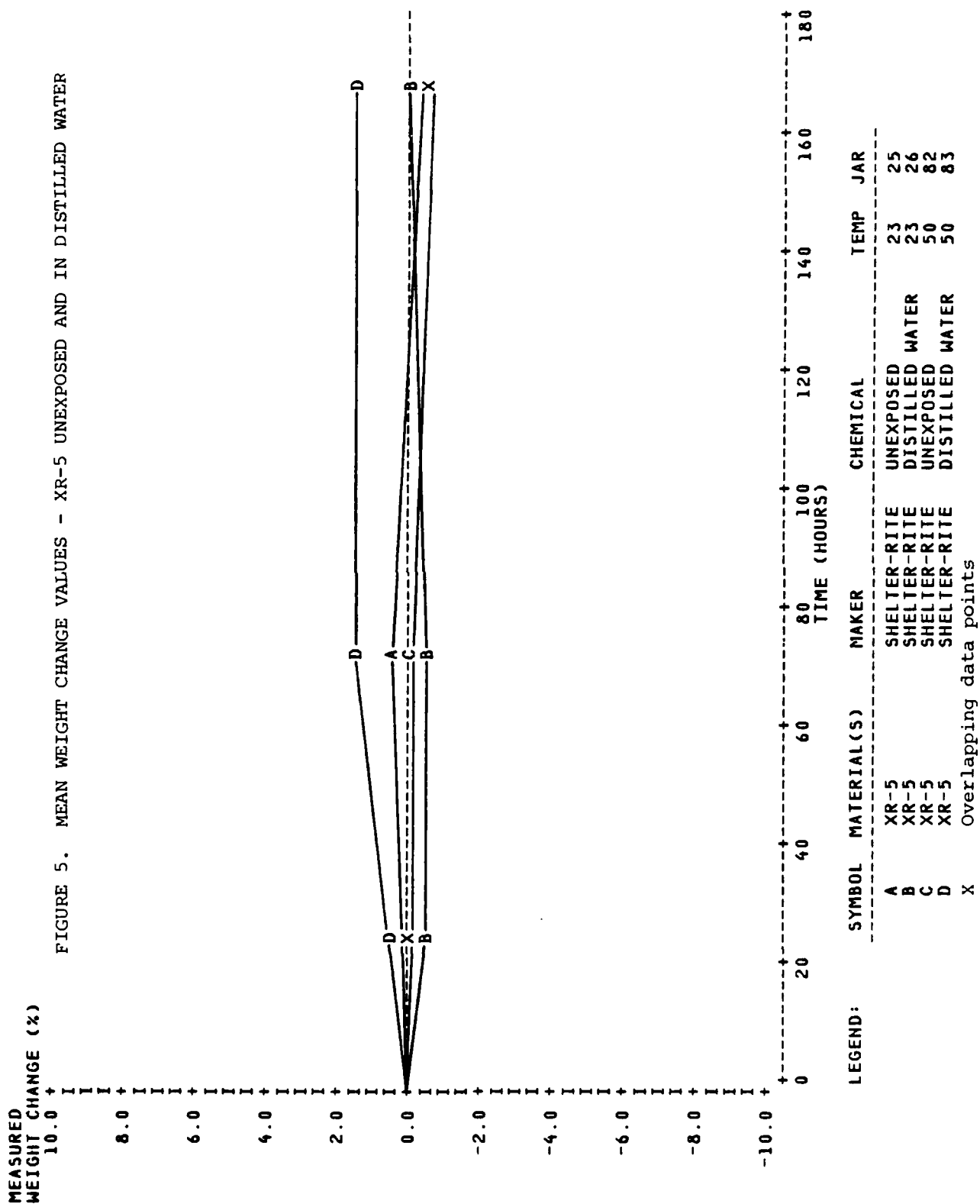
MEASURED
WEIGHT CHANGE (%)

FIGURE 4. MEAN WEIGHT CHANGE VALUES - HDPE UNEXPOSED AND IN DISTILLED WATER



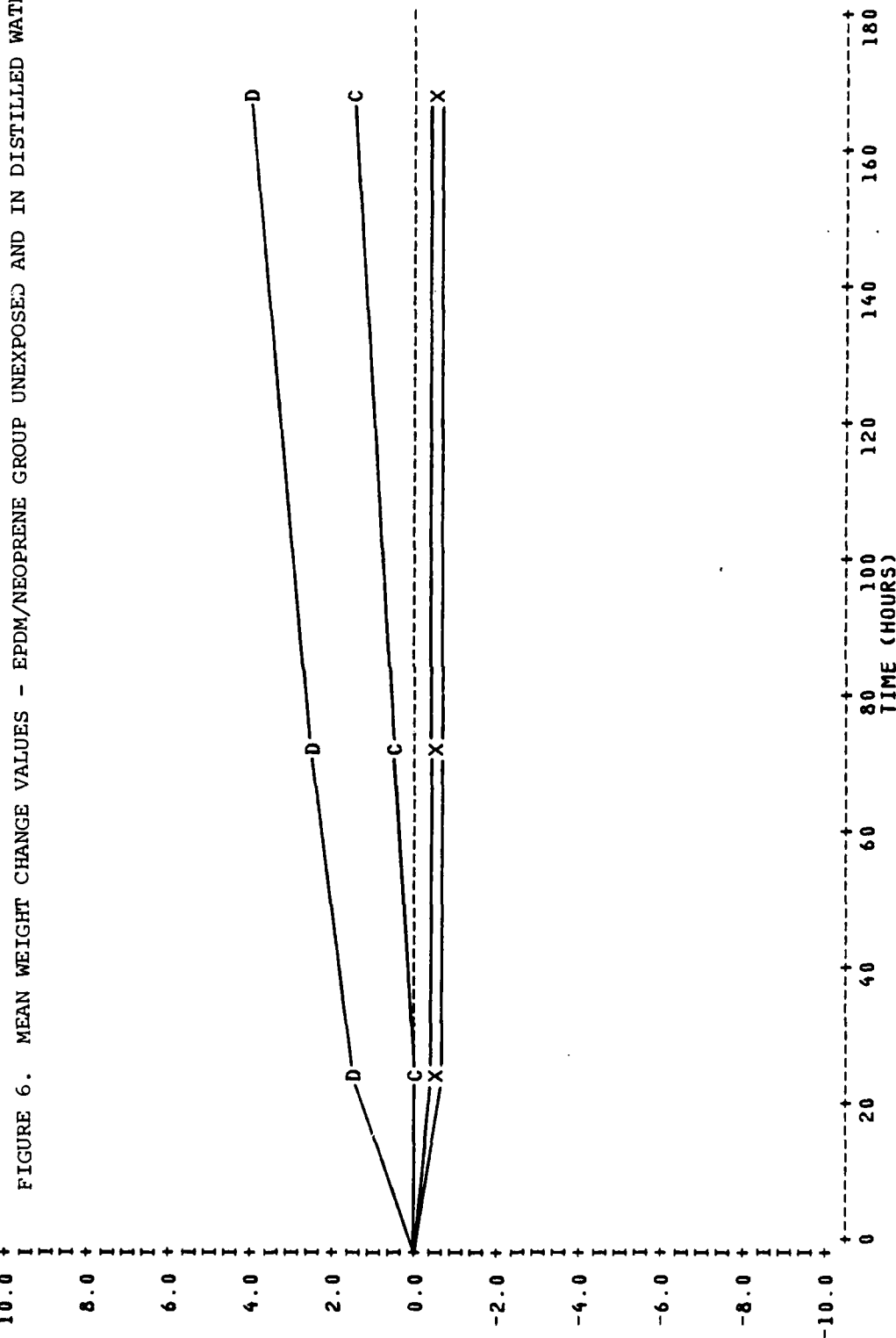
LEGEND:

SYMBOL	MATERIAL(S)	MAKER	CHEMICAL	TEMP	JAR
A	HDPE	SCHLEGEL	UNEXPOSED	23	22
B	HDPE	SCHLEGEL	DISTILLED WATER	23	23
C	HDPE	SCHLEGEL	UNEXPOSED	50	78
D	HDPE	SCHLEGEL	DISTILLED WATER	50	79
X	Overlapping data points				



MEASURED
WEIGHT CHANGE (%)

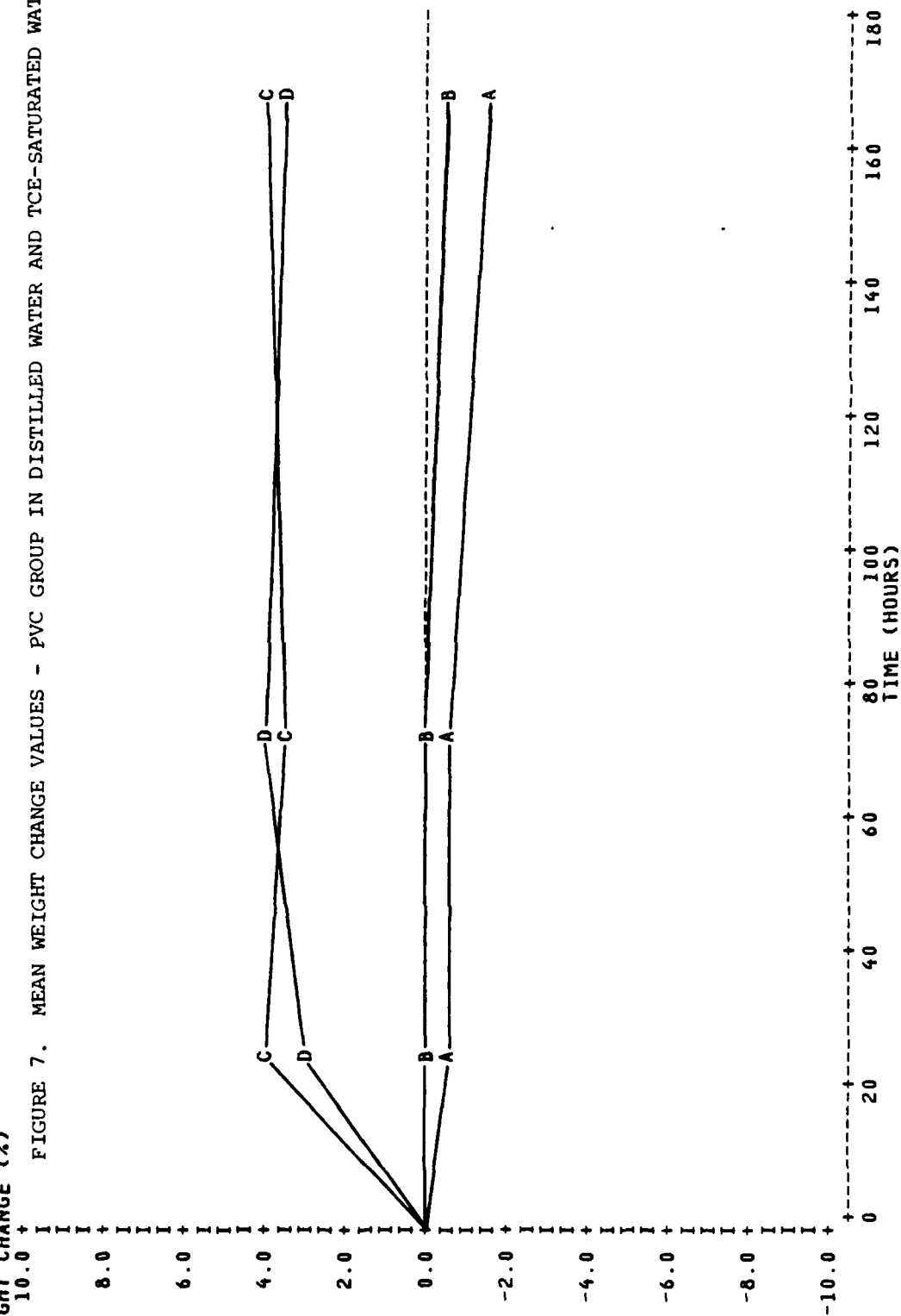
FIGURE 6. MEAN WEIGHT CHANGE VALUES - EPDM/NEOPRENE GROUP UNEXPOSED AND IN DISTILLED WATER



LEGEND:	SYMBOL	MATERIAL(S)	MAKER	CHEMICAL	TEMP	JAR
	A	EPDM/NEO	GROUP	UNEXPOSED	23	160
	B	EPDM/NEO	GROUP	UNEXPOSED	50	161
	C	EPDM/NEO	GROUP	DISTILLED WATER	23	162
	D	EPDM/NEO	GROUP	DISTILLED WATER	50	163
	X	Overlapping data points				

MEASURED
WEIGHT CHANGE (%)

FIGURE 7. MEAN WEIGHT CHANGE VALUES - PVC GROUP IN DISTILLED WATER AND TCE-SATURATED WATER

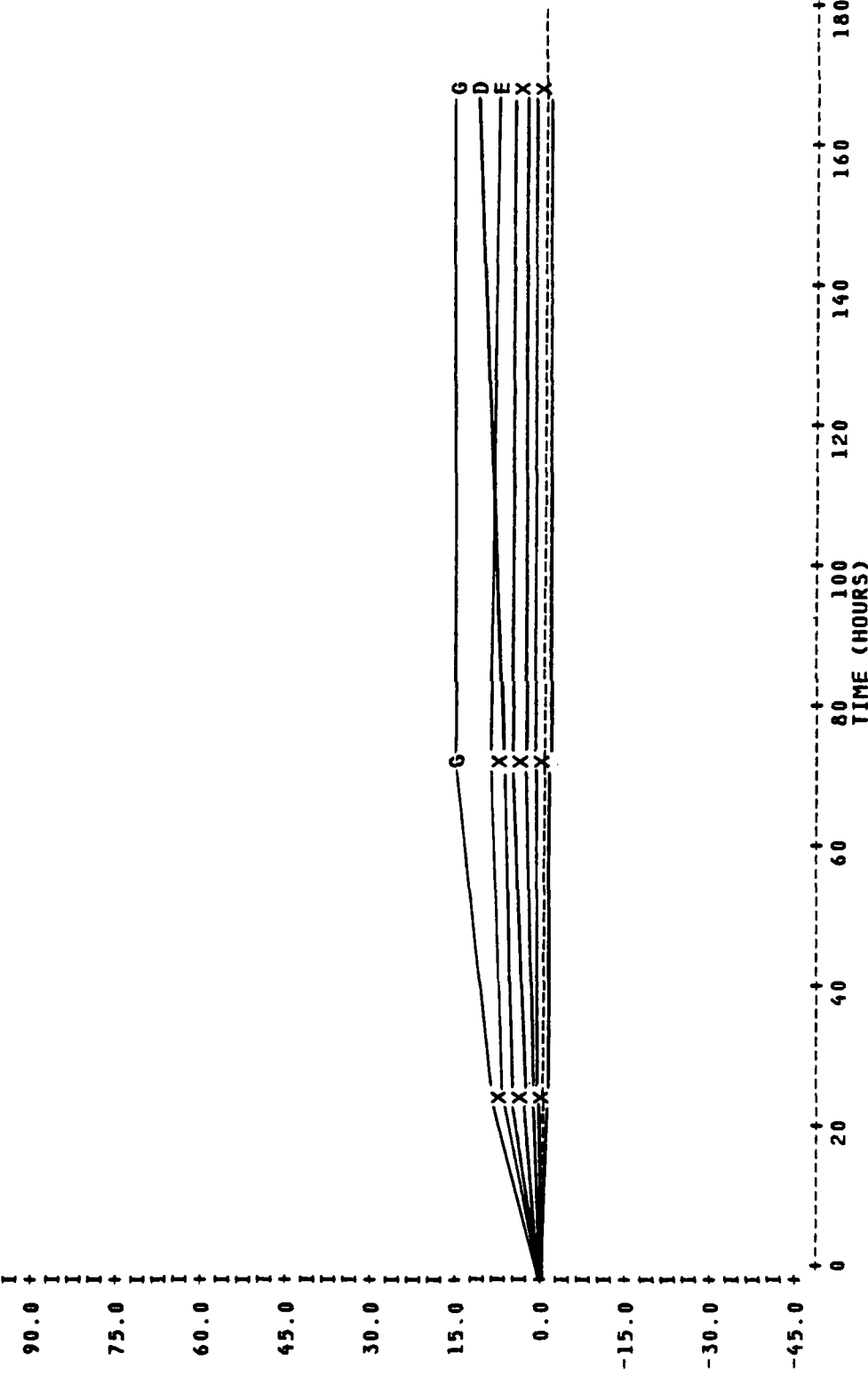


LEGEND:

SYMBOL	MATERIAL(S)	MAKER	CHEMICAL	TEMP	JAR
A	PV/PV-OR	GROUP	DISTILLED WATER	23	152
B	PV/PV-OR	GROUP	DISTILLED WATER	50	153
C	PV/PV-OR	GROUP	TCE-SAT'D WATER	23	155
D	PV/PV-OR	GROUP	TCE-SAT'D WATER	50	156

MEASURED
WEIGHT CHANGE (%)

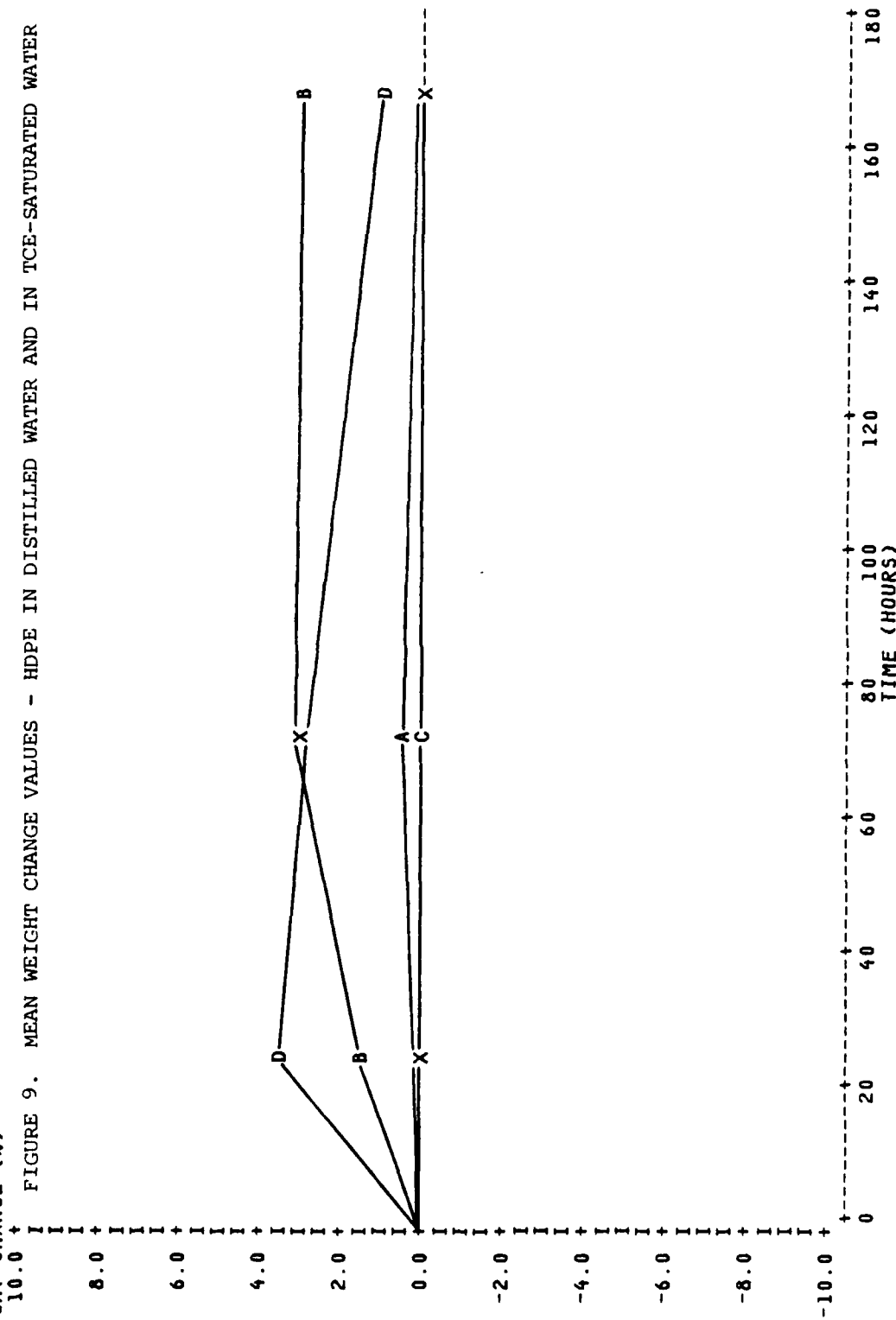
FIGURE 8. MEAN WEIGHT CHANGE VALUES - CPE/HYPALON GROUP IN DISTILLED WATER AND
N TCE-SATURATED WATER



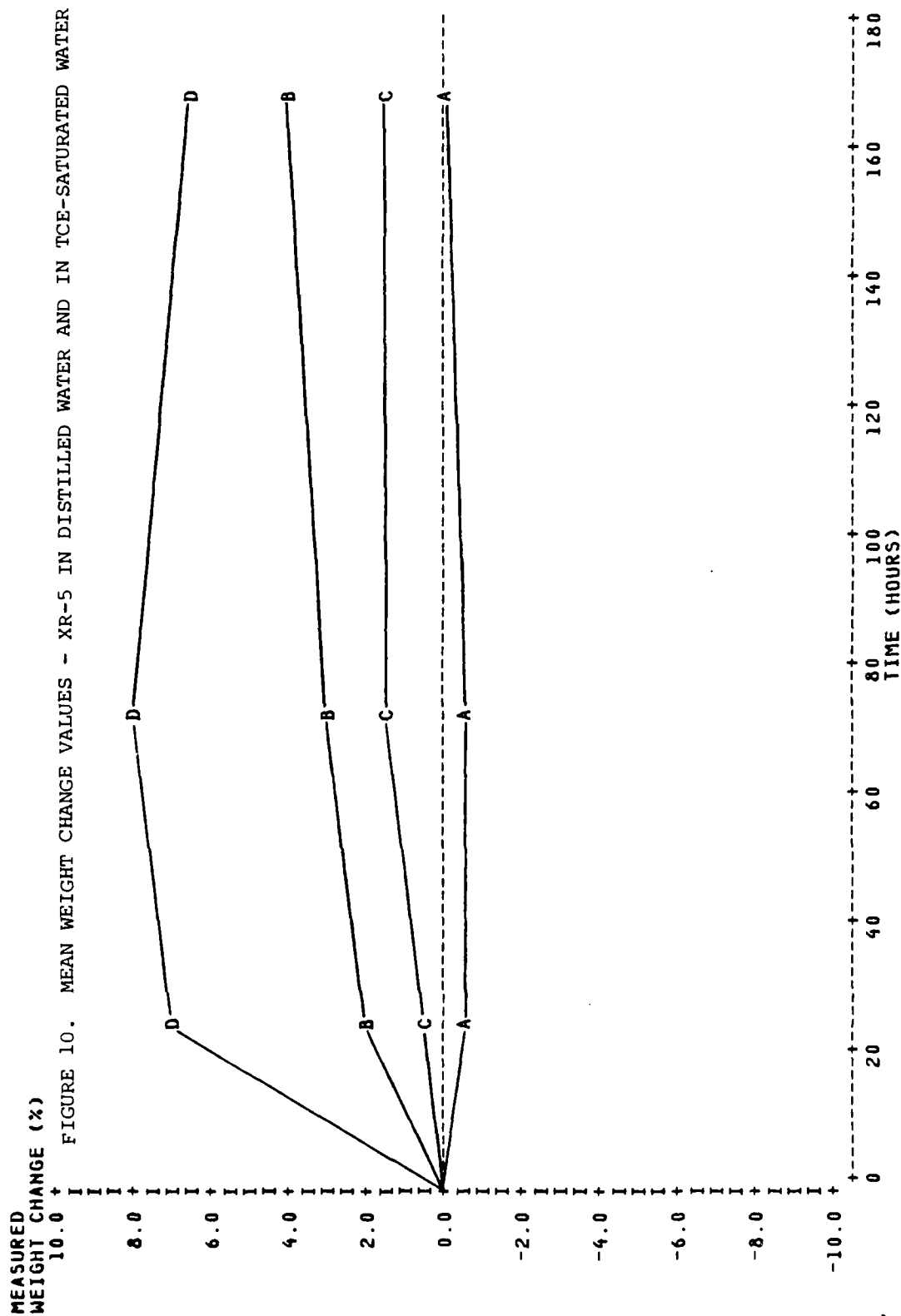
LEGEND:	SYMBOL	MATERIAL(S)	MAKER	CHEMICAL	TEMP	JAR
	A	PV/PV-OR	GROUP	DISTILLED WATER	23	173
	B	CPE	GROUP	DISTILLED WATER	50	174
	C	HYPALON	GROUP	DISTILLED WATER	50	175
	D	CPE	GROUP	TCE-SAT'D WATER	50	178
	E	HYPALON	GROUP	TCE-SAT'D WATER	50	179
	F	HYPALON	GROUP	TCE-SAT'D WATER	23	180
	G	CPE	PANTASOTE	TCE-SAT'D WATER	23	181
	X	Overlapping data points				

MEASURED
WEIGHT CHANGE (%)

FIGURE 9. MEAN WEIGHT CHANGE VALUES - HDPE IN DISTILLED WATER AND IN TCE-SATURATED WATER

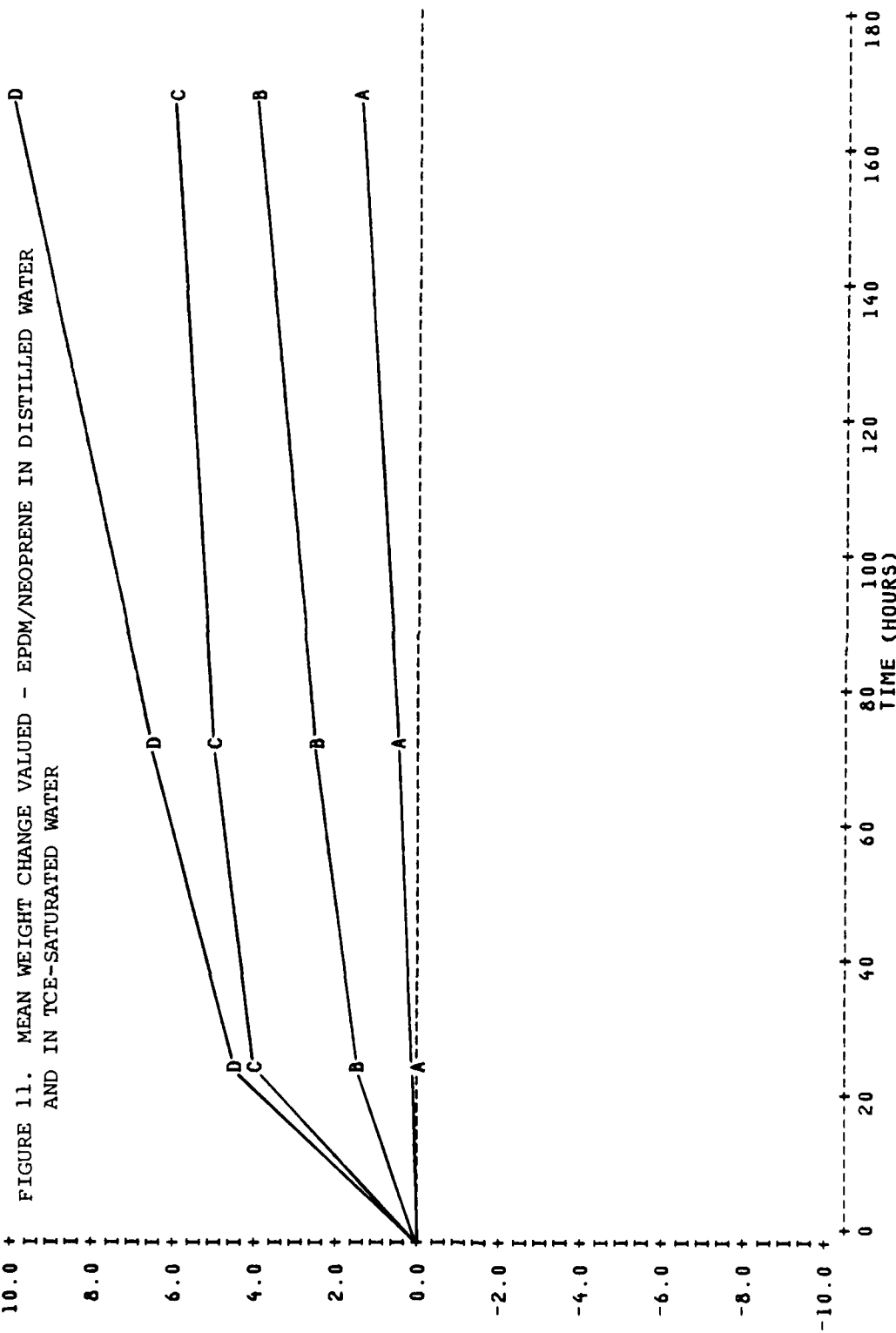


LEGEND:	SYMBOL	MATERIAL(S)	MAKER	CHEMICAL	TEMP	JAR
	A	HDPE	SCHLEGEL	DISTILLED WATER	23	23
	B	HDPE	SCHLEGEL	TCE-SAT'D WATER	23	24
	C	HDPE	SCHLEGEL	DISTILLED WATER	50	79
	D	HDPE	SCHLEGEL	TCE-SAT'D WATER	50	81
	X	Overlapping data points				



LEGEND:	SYMBOL	MATERIAL(S)	MAKER	CHEMICAL	TEMP	JAR
	A	XR-5	SHELTER-RITE	DISTILLED WATER	23	26
	B	XR-5	SHELTER-RITE	TCE-SAT'D WATER	23	27
	C	XR-5	SHELTER-RITE	DISTILLED WATER	50	83
	D	XR-5	SHELTER-RITE	TCE-SAT'D WATER	50	85

MEASURED
WEIGHT CHANGE (%)



LEGEND:

SYMBOL	MATERIAL(S)	MAKER	CHEMICAL	TEMP	JAR
A	EPDM/NEO	GROUP	DISTILLED WATER	23	162
B	EPDM/NEO	GROUP	DISTILLED WATER	50	163
C	EPDM/NEO	GROUP	TCE-SAT'D WATER	23	165
D	EPDM/NEO	GROUP	TCE-SAT'D WATER	50	166

All of the liner groups showed an increase in weight for the immersion in TCE-saturated water relative to those in distilled water. In all cases the weight increase attributable to TCE was rapid, occurring within the first 24 hours. Thereafter, the weights of the samples held constant or decreased relative to those for the distilled water immersions.

The TCE-saturated water had the greatest effect on the CPE and Hypalon liner groups causing weight increases of 10 to 15 percent. The PVC/PVC-OR, EPDM/Neoprene, and XR-5 liner groups had weight increases of four to six percent attributable to the TCE saturated water. TCE-saturated water had a limited effect on the HDPE samples, resulting in a weight increase of approximately three percent. Temperature appeared to have little effect on weight increases for samples immersed in TCE-saturated water solutions. The weight increases at 23°C and 50°C were similar in magnitude with some exceptions. The exceptions were that at 50°C the weight increase was greater for the XR-5 samples, and the XR-5 and HDPE samples decreased in weight between the third and seventh days of immersion.

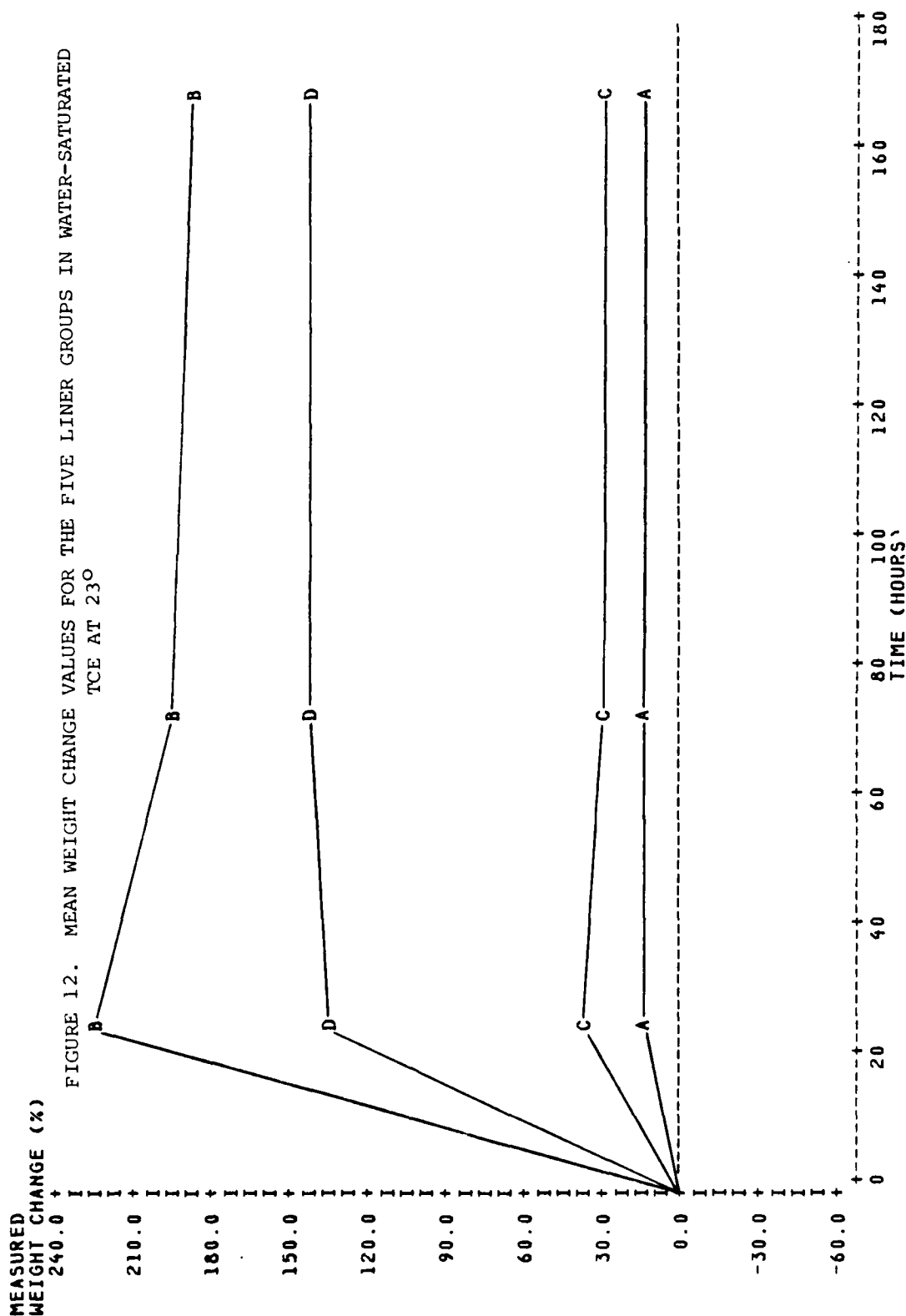
Water-Saturated TCE

The weight changes for samples immersed in the water-saturated TCE at 23°C are presented in Figure 12 for the PVC/PVC-OR, EPDM/Neoprene, HDPE and XR-5 liner groups. The CPE/Hypalon samples are not included because they were dissolved within 24 hours. All other liner groups showed significant and rapid weight increases with the weight increases occurring within one day for the PVC/PVC-OR, HDPE and XR-5 liner group and within three days for the EPDM/Neoprene liner group.

The weight increases for both the XR-5 and EPDM/Neoprene liner groups exceeded 140 percent, whereas those for PVC/PVC-OR and HDPE were approximately 30 percent and 15 percent respectively. With the exception of the XR-5 samples, the weights of the samples remained constant during the 7-day immersion period. The weight of the XR-5 liner samples decreased approximately 35 percent between the first and the seventh days of the immersion period, from a 225 percent increase to 188 percent.

TNT-Saturated Water

The weight changes for distilled water immersions at 23°C and 50°C and for TNT-saturated water at 50°C are presented in Figures 13 through 17. With the exception of the HDPE samples, all the liner groups showed an increase in weight change for the TNT-saturated water immersions relative to the distilled water immersions. Additionally, with the exception of the HDPE samples, the difference between the weight changes for the TNT-saturated water and those for the distilled water immersions continued to increase during the 7-day immersion period. The increase exceeded two percent for the PVC/PVC-OR, CPE, and XR-5 liner groups by the seventh day. The HDPE samples show no change during the seven day immersion period and the Hypalon and EPDM/Neoprene liner groups increased in weight by less than two percent.



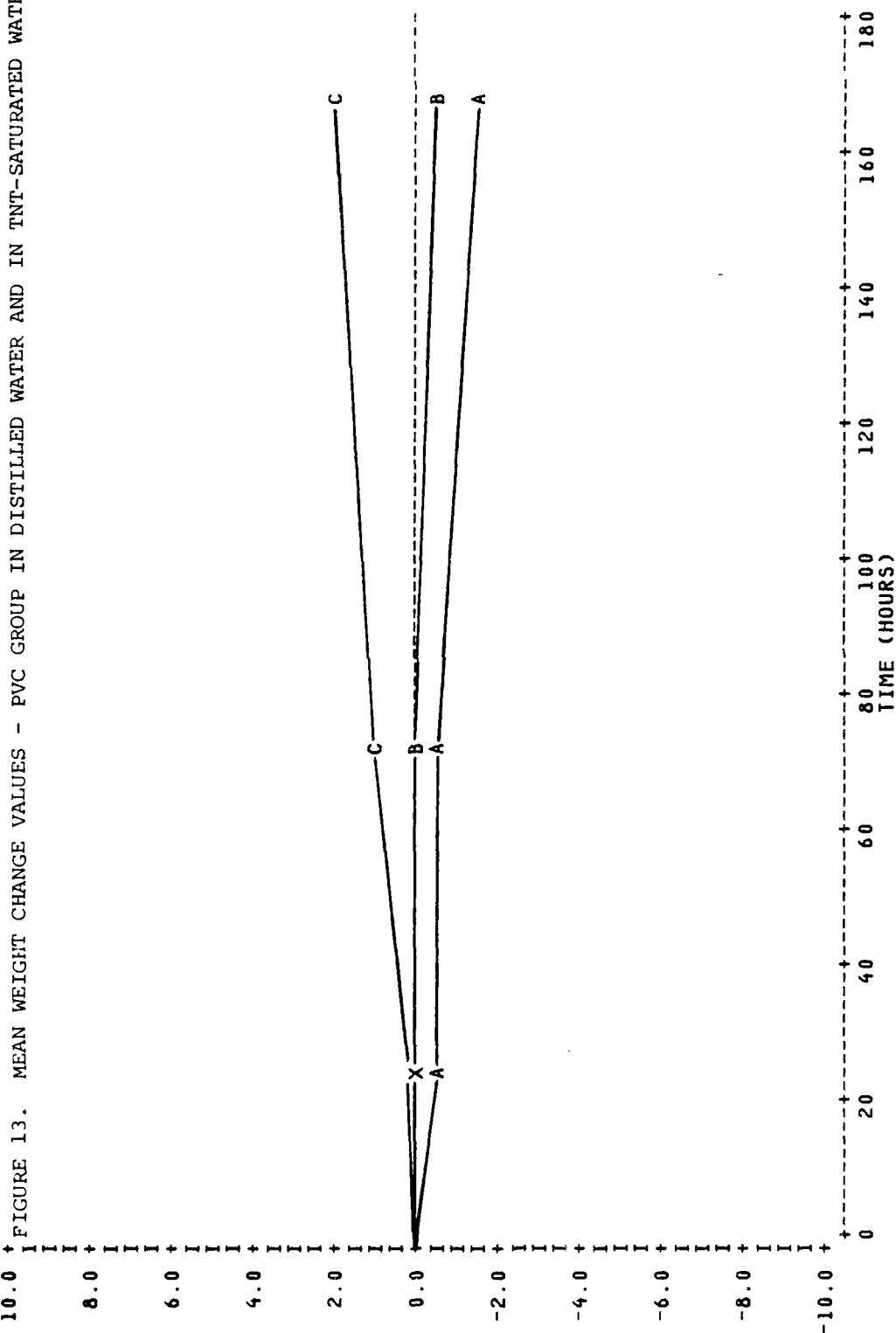
LEGEND:

SYMBOL	MATERIAL(S)	MAKER	CHEMICAL	TEMP	JAR
A	HDPE	SCHLEGEL	WATER-SAT'D TCE	23	42
B	XR-5	SHELTER-RITE	WATER-SAT'D TCE	23	43
C	PV/PV-OR	GROUP	WATER-SAT'D TCE	23	157
D	EPDM/NEO	GROUP	WATER-SAT'D TCE	23	167

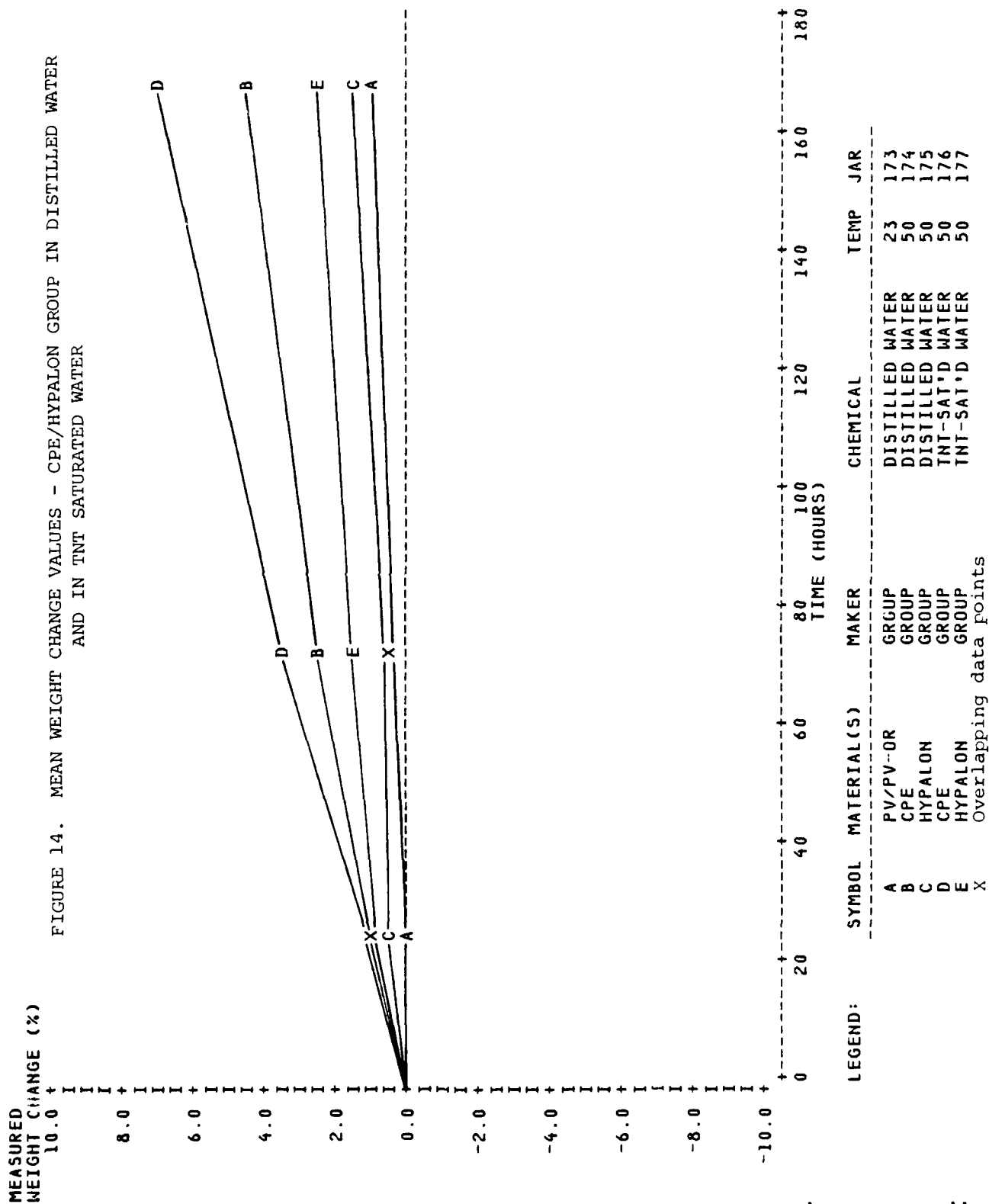
Note: All the CPE/Hypalon group samples dissolved with in 24 hours.

MEASURED WEIGHT CHANGE (%)

FIGURE 13. MEAN WEIGHT CHANGE VALUES - PVC GROUP IN DISTILLED WATER AND IN TNT-SATURATED WATER

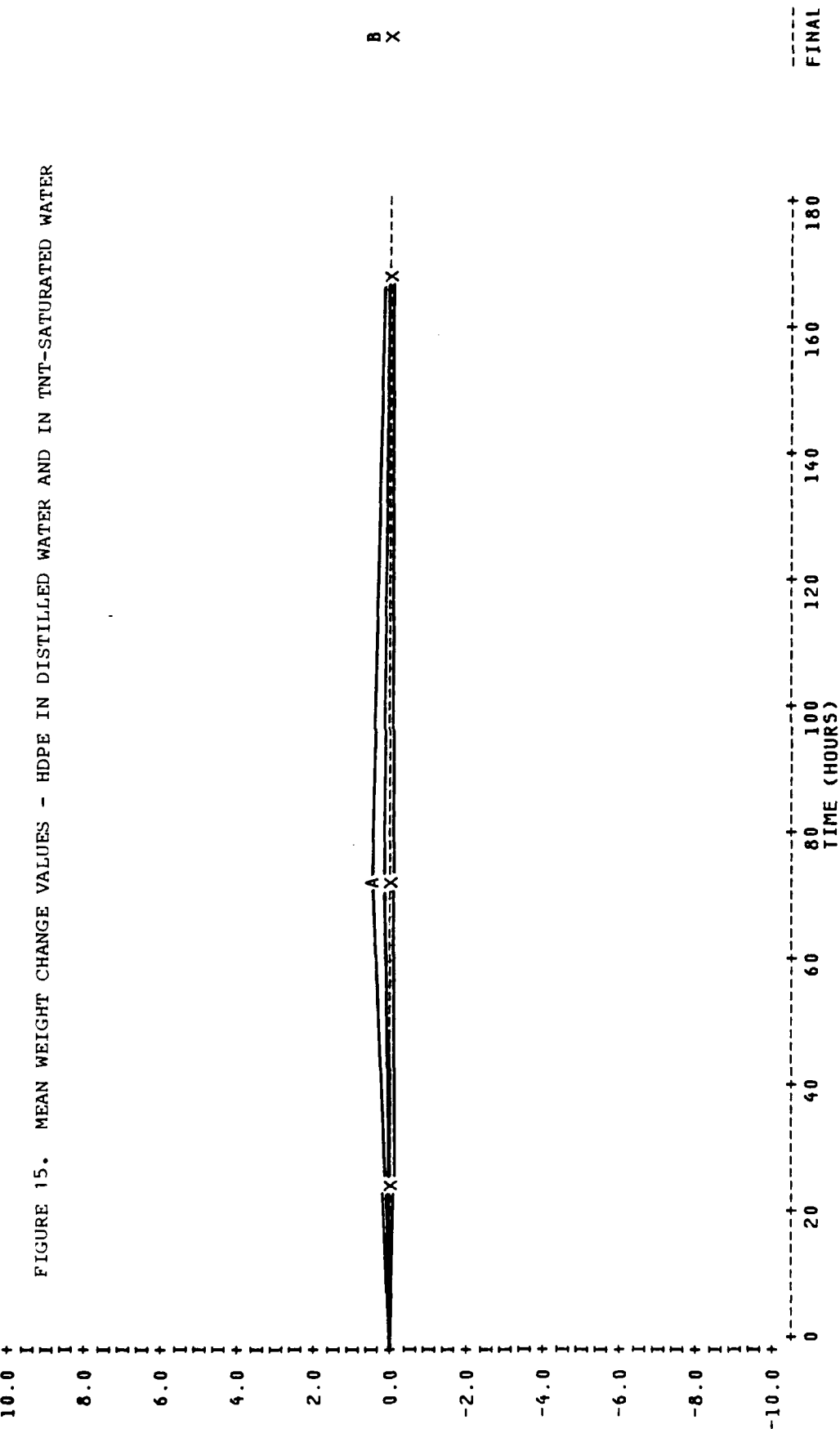


LEGEND:	SYMBOL	MATERIAL(S)	MAKER	CHEMICAL	TEMP	JAR
	A	PV/PV-OR	GROUP	DISTILLED WATER	23	152
	B	PV/PV-OR	GROUP	DISTILLED WATER	50	153
	C	PV/PV-OR	GROUP	TNT-SAT'D WATER	50	154
	X	Overlapping data points				



MEASURED
WEIGHT CHANGE (%)

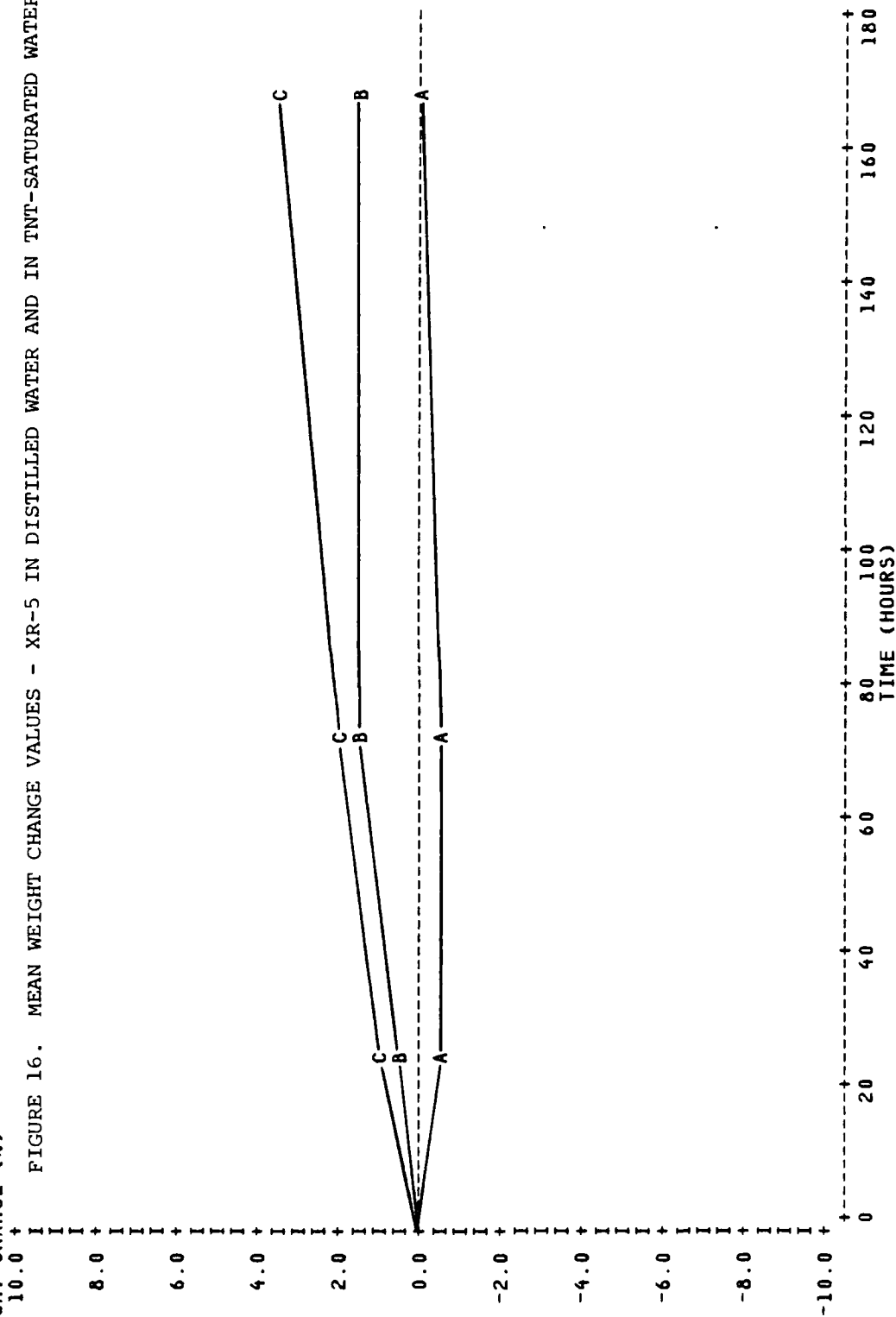
FIGURE 15. MEAN WEIGHT CHANGE VALUES - HDPE IN DISTILLED WATER AND IN TNT-SATURATED WATER



LEGEND:	SYMBOL	MATERIAL	MAKER	CHEMICAL	TEMP	JAR
	A	HDPE	SCHLEGEL	DISTILLED WATER	23	23
	B	HDPE	SCHLEGEL	DISTILLED WATER	50	79
	C	HDPE	SCHLEGEL	TNT-SAT'D WATER	50	80
	X	Overlapping data points				

MEASURED
WEIGHT CHANGE (%)

FIGURE 16. MEAN WEIGHT CHANGE VALUES - XR-5 IN DISTILLED WATER AND IN TNT-SATURATED WATER

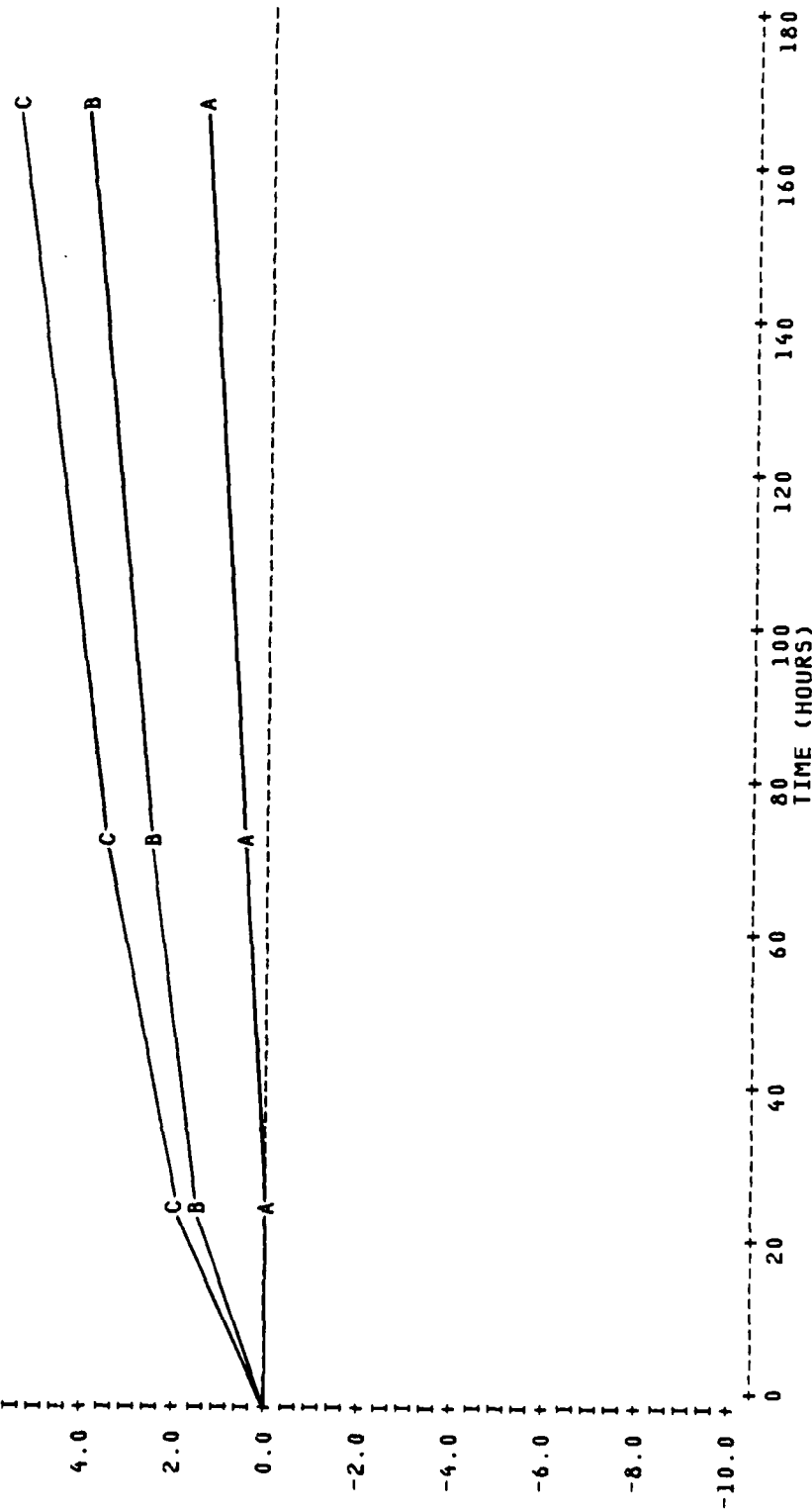


LEGEND:

SYMBOL	MATERIAL(S)	MAKER	CHEMICAL	TEMP	JAR
A	XR-5	SHELTER-RITE	DISTILLED WATER	23	26
B	XR-5	SHELTER-RITE	DISTILLED WATER	50	83
C	XR-5	SHELTER-RITE	TNT-SAT'D WATER	50	84

MEASURED
WEIGHT CHANGE (%)

FIGURE 17. MEAN WEIGHT CHANGE VALUES - EPDM/NEOPRENE GROUP IN DISTILLED WATER AND
IN TNT-SATURATED WATER



LEGEND:

SYMBOL	MATERIAL(S)	MAKER	CHEMICAL	TEMP	JAR
A	EPDM/NEO	GROUP	DISTILLED WATER	23	162
B	EPDM/NEO	GROUP	DISTILLED WATER	50	163
C	EPDM/NEO	GROUP	TNT-SAT'D WATER	50	164

RDX-Saturated Water

The weight changes for the distilled water immersions at 23°C and 50°C and for the RDX-saturated water immersions at 50°C are presented in Figures 18 through 25. Three of the basic groups (PVC, CPE/Hypalon and EPDM/Neoprene) were further subdivided to be consistent with the liner grouping criteria. This subdivision resulted in the development of seven liner groups for RDX.

After this initial complication, it was found that Neoprene and CPE were the only two liner groups to show a divergence in weight change during immersion relative to the distilled water at 50°C. The divergence was small (approximately one percent for Neoprene; slightly less for CPE) and therefore not viewed as a significant factor.

DRIED WEIGHT CHANGE AND ABSORBANCE

The quantitative results for dried weight change and absorbance are presented in Tables 15 to 24. These parameters were calculated using equations 3 and 4 (Chapter 4). The observations below are referenced to the individual tables.

Unexposed/Distilled Water (23°C)

A comparison of the dried weight changes between the unexposed samples (control) and the samples immersed in distilled water at 23°C is presented in Table 15. The liners immersed in distilled water showed no significant difference from the control (unexposed) samples for all the liner groups at 23°C.

A comparison of the absorbance between unexposed samples (control) and samples immersed in distilled water at 23°C is presented in Table 16. Three of the groups, CPE/Hypalon, XR-5 and EPDM/Neoprene, showed slight increase in absorbance from the control (unexposed) samples after being immersed in distilled water at 23°C. These increases were only 0.8 to 1.5 percent, but were sufficient to warrant the use of the distilled water immersions as the control for the test solution immersions.

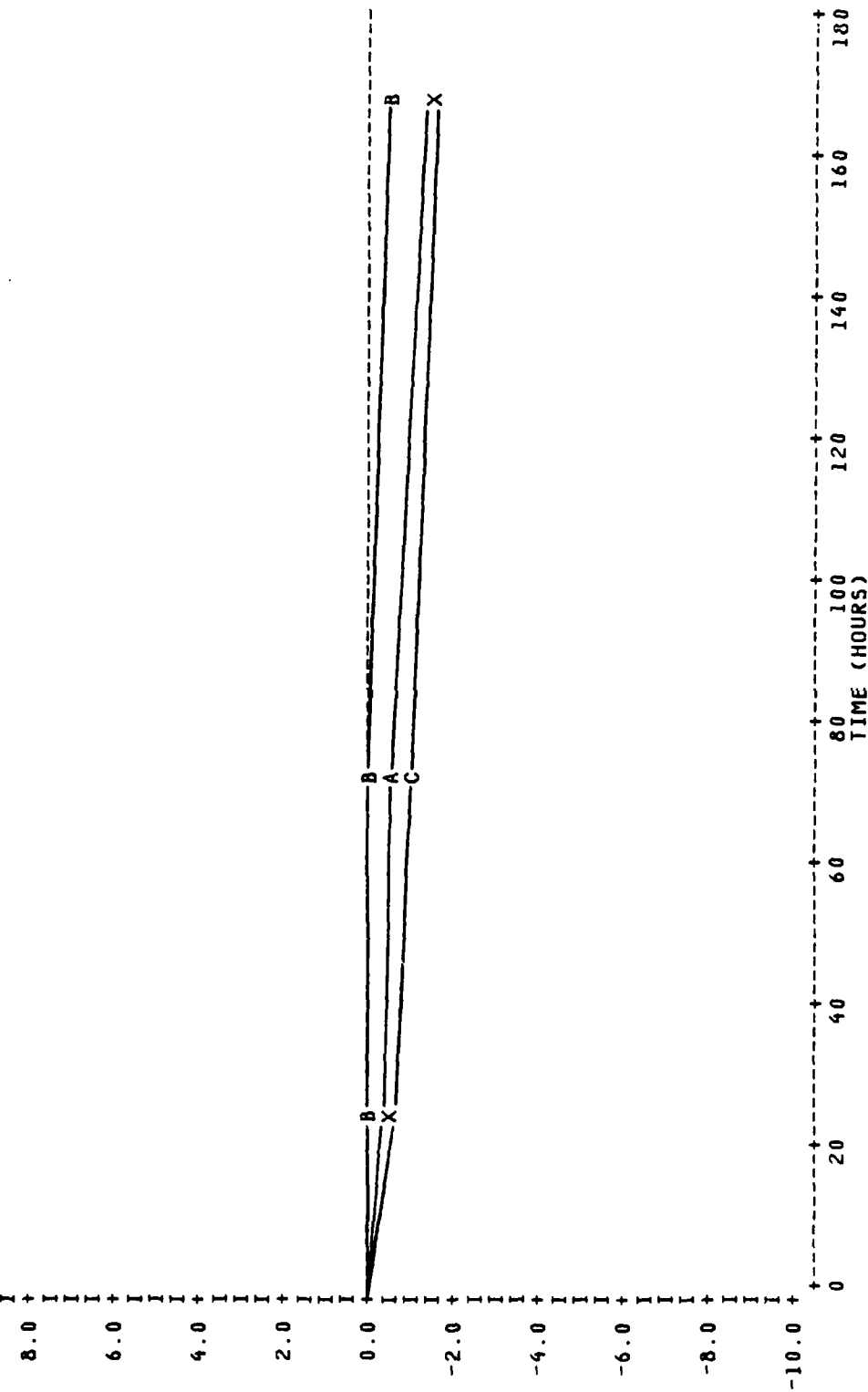
Unexposed/Distilled Water (50°C)

A comparison of the dried weight change between unexposed samples (control) and samples immersed in distilled water at 50°C is presented in Table 17. The liners immersed in distilled water also showed no significant difference from the control (unexposed) sample at 50°C.

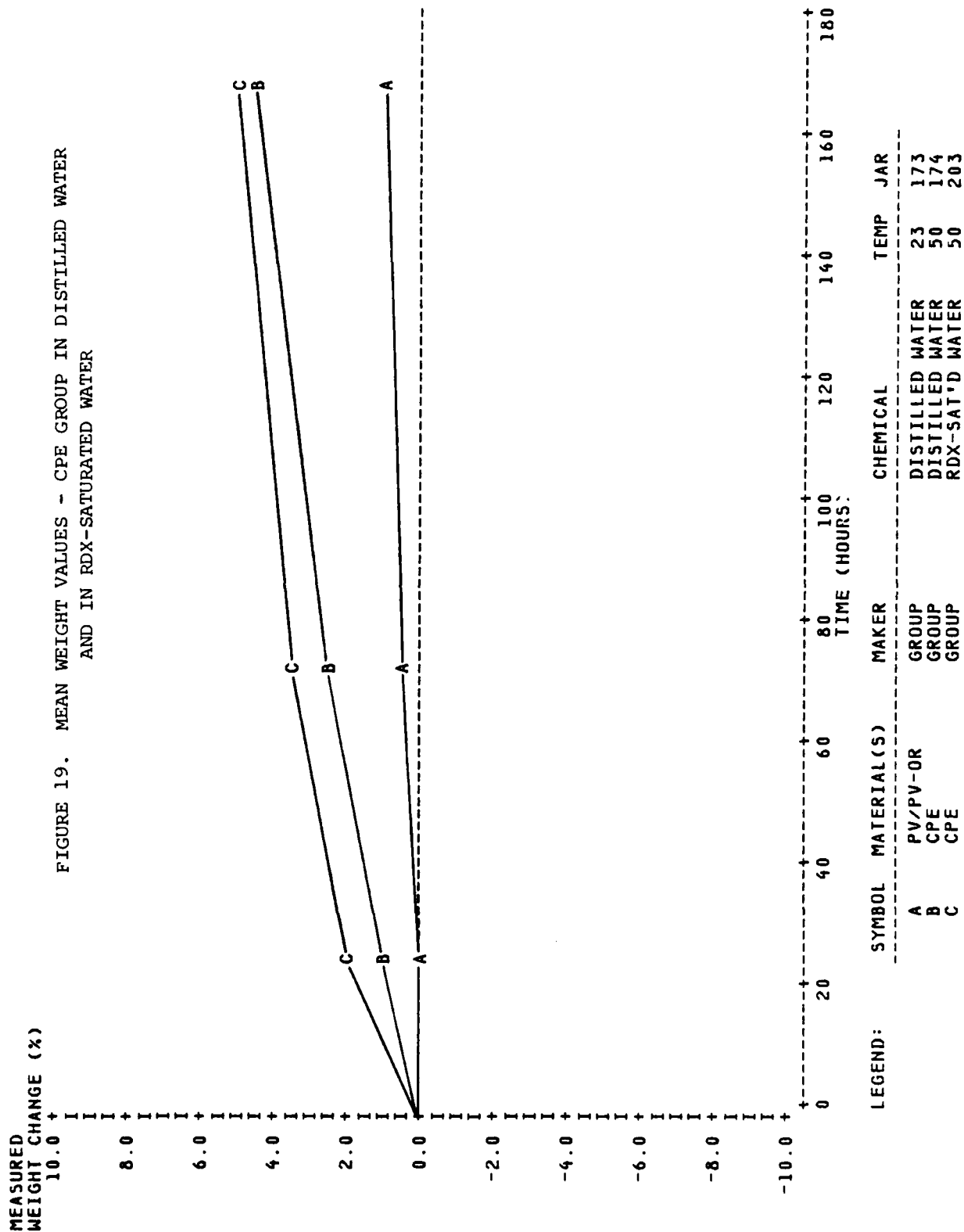
A comparison of the absorbance between unexposed (control) samples and samples immersed in distilled water at 50°C is presented in Table 18. The CPE liner group showed a 5.04 percent increase in absorbance when immersed in distilled water at 50°C relative to the control.

MEASURED
WEIGHT CHANGE (%)

FIGURE 18. MEAN WEIGHT CHANGE VALUES - PVC GROUP IN DISTILLED WATER
AND IN RDX-SATURATED WATER

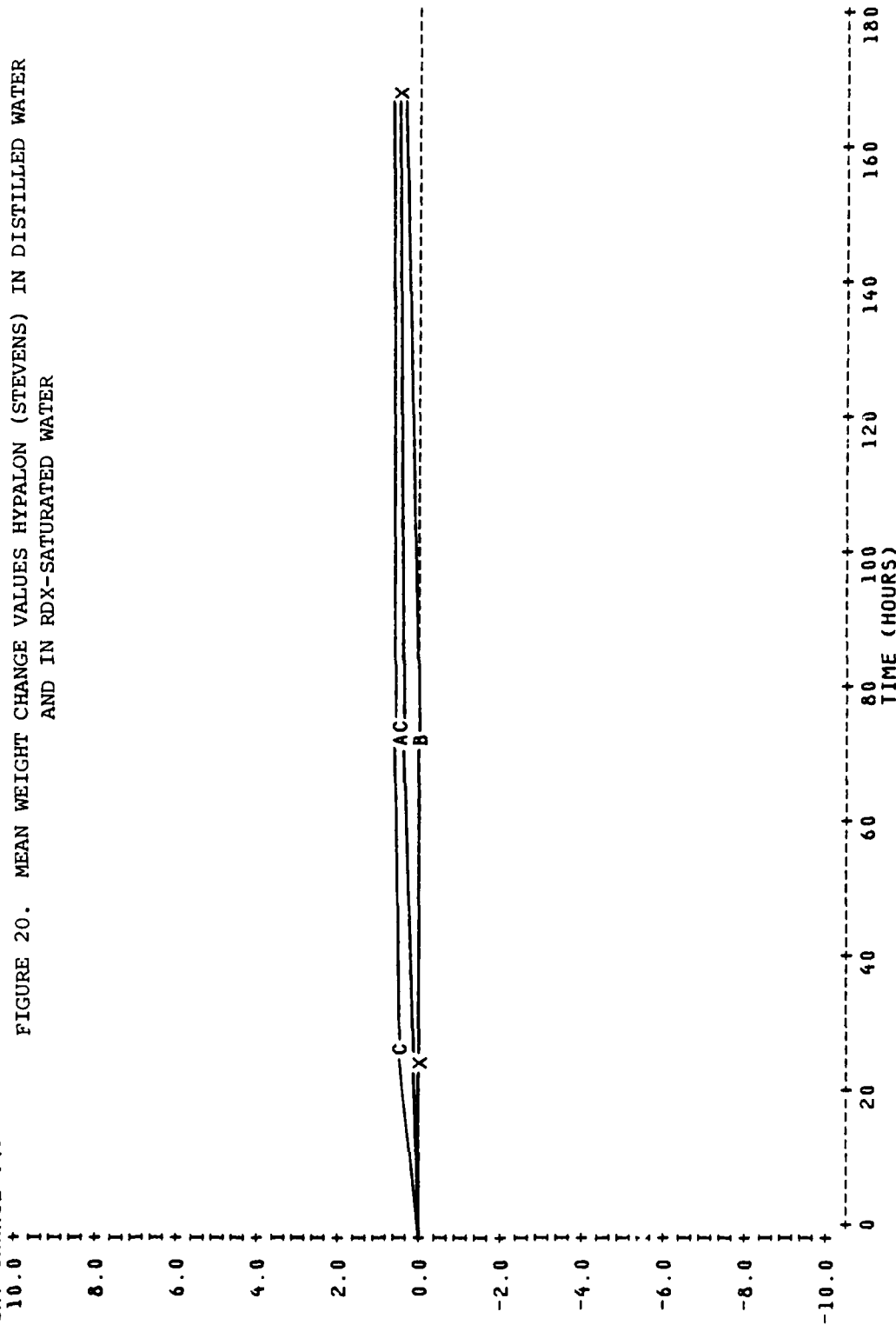


LEGEND:	SYMBOL	MATERIAL(S)	MAKER	CHEMICAL	TEMP	JAR
	A	PV/PV-OR	GROUP	DISTILLED WATER	23	152
	B	PV/PV-OR	GROUP	DISTILLED WATER	50	153
	C	PV/PV-OR	GROUP	RDX-SAT'D WATER	50	200
	X	Overlapping data points				

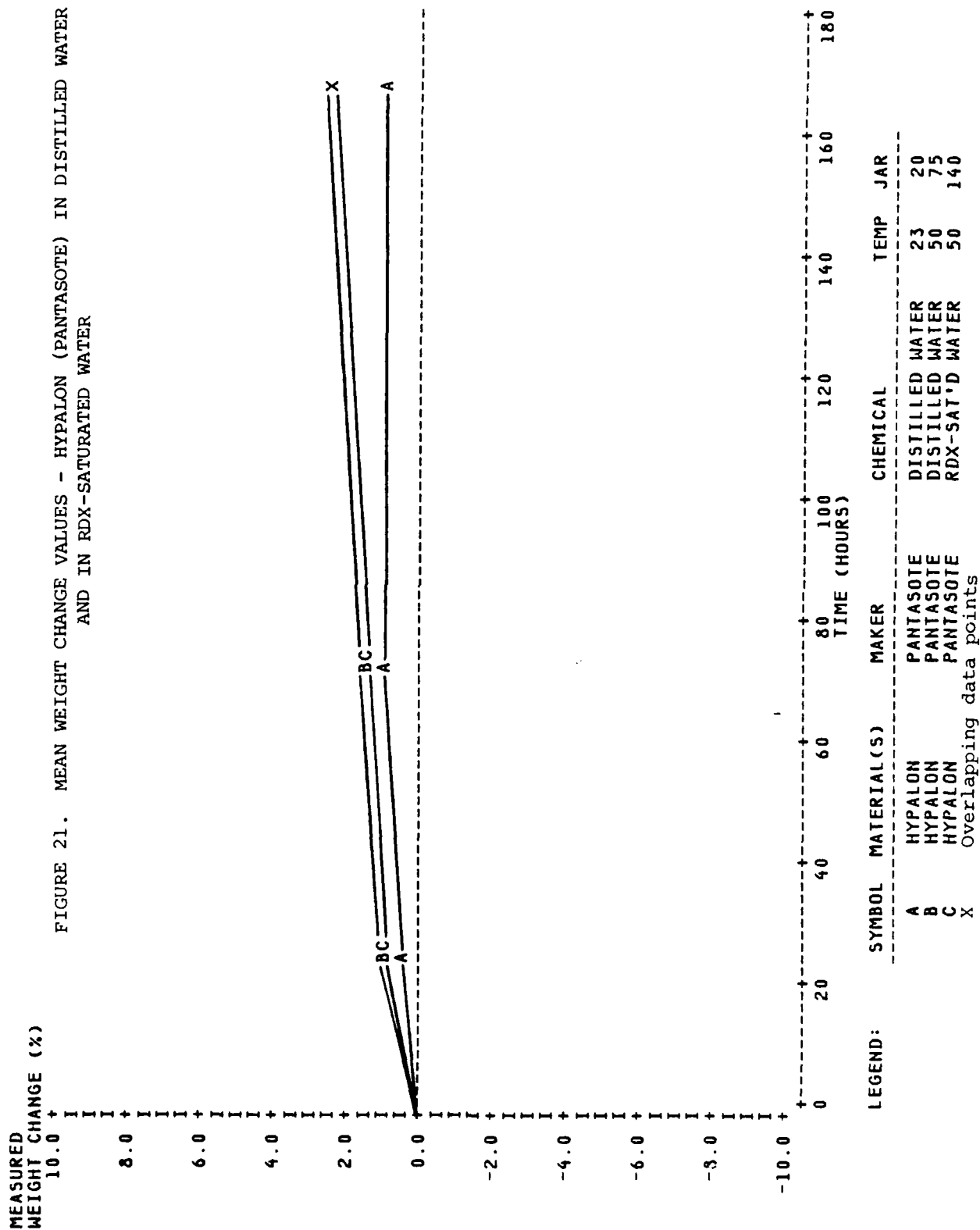


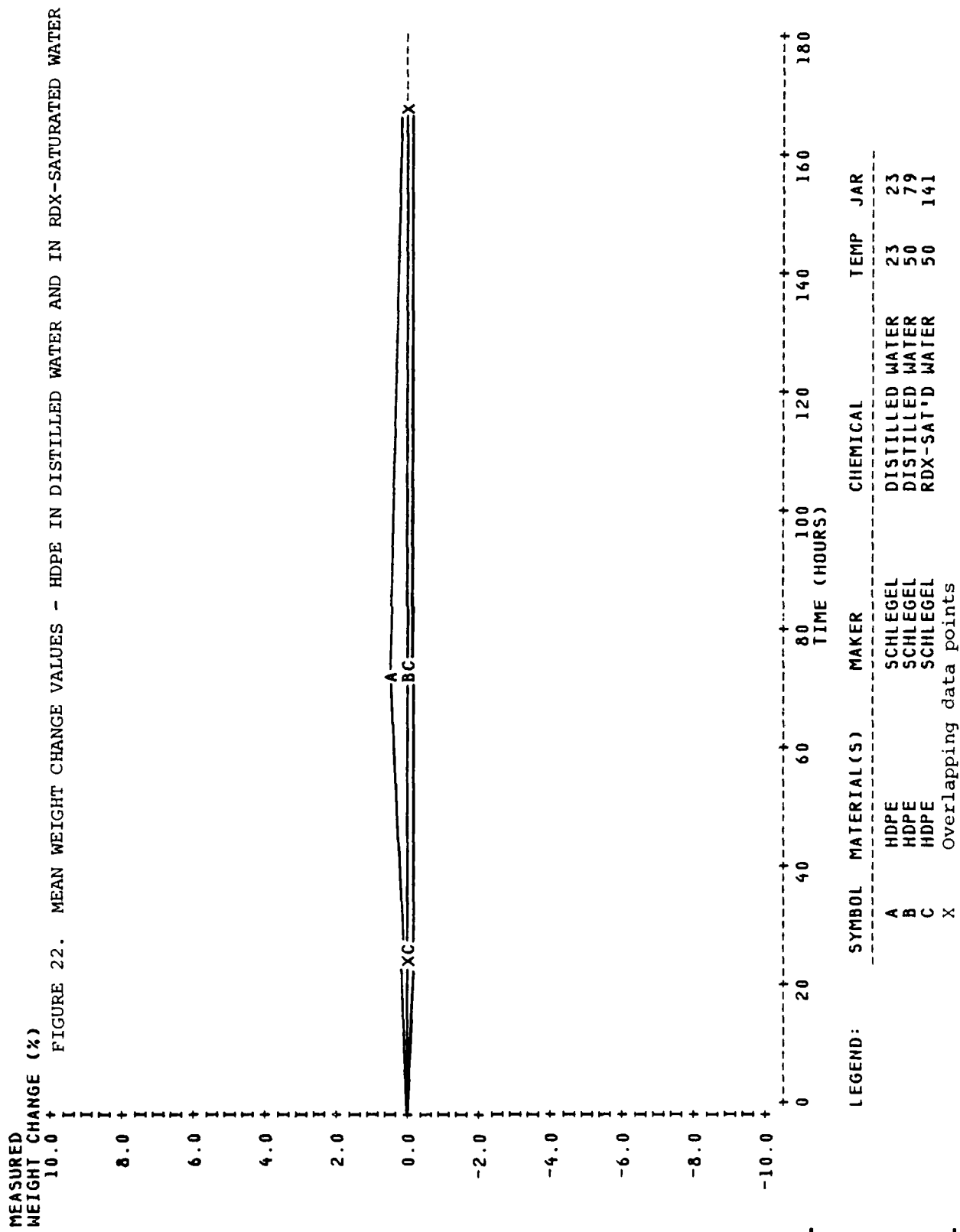
MEASURED
WEIGHT CHANGE (%)

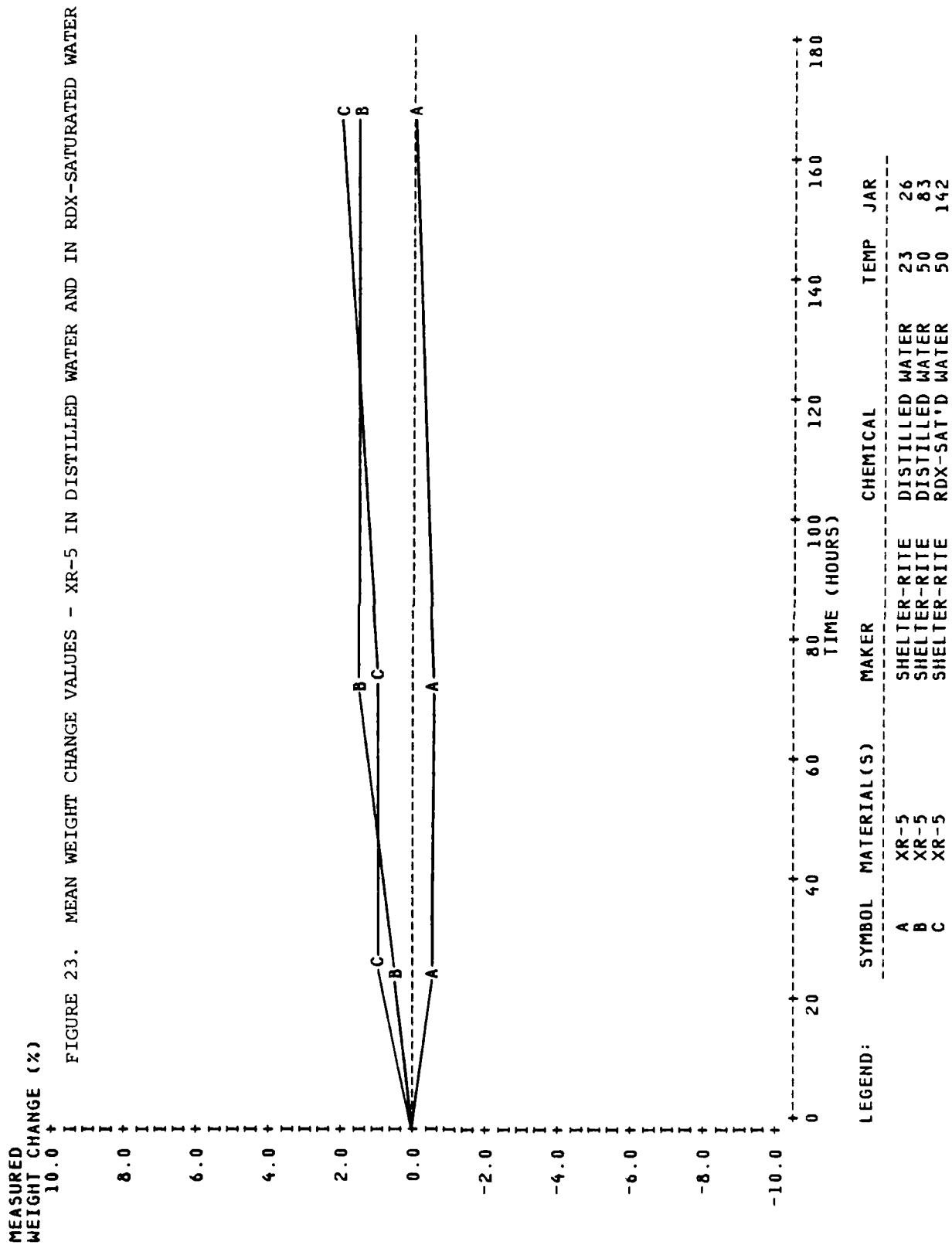
FIGURE 20. MEAN WEIGHT CHANGE VALUES HYPALON (STEVENS) IN DISTILLED WATER
AND IN RDX-SATURATED WATER

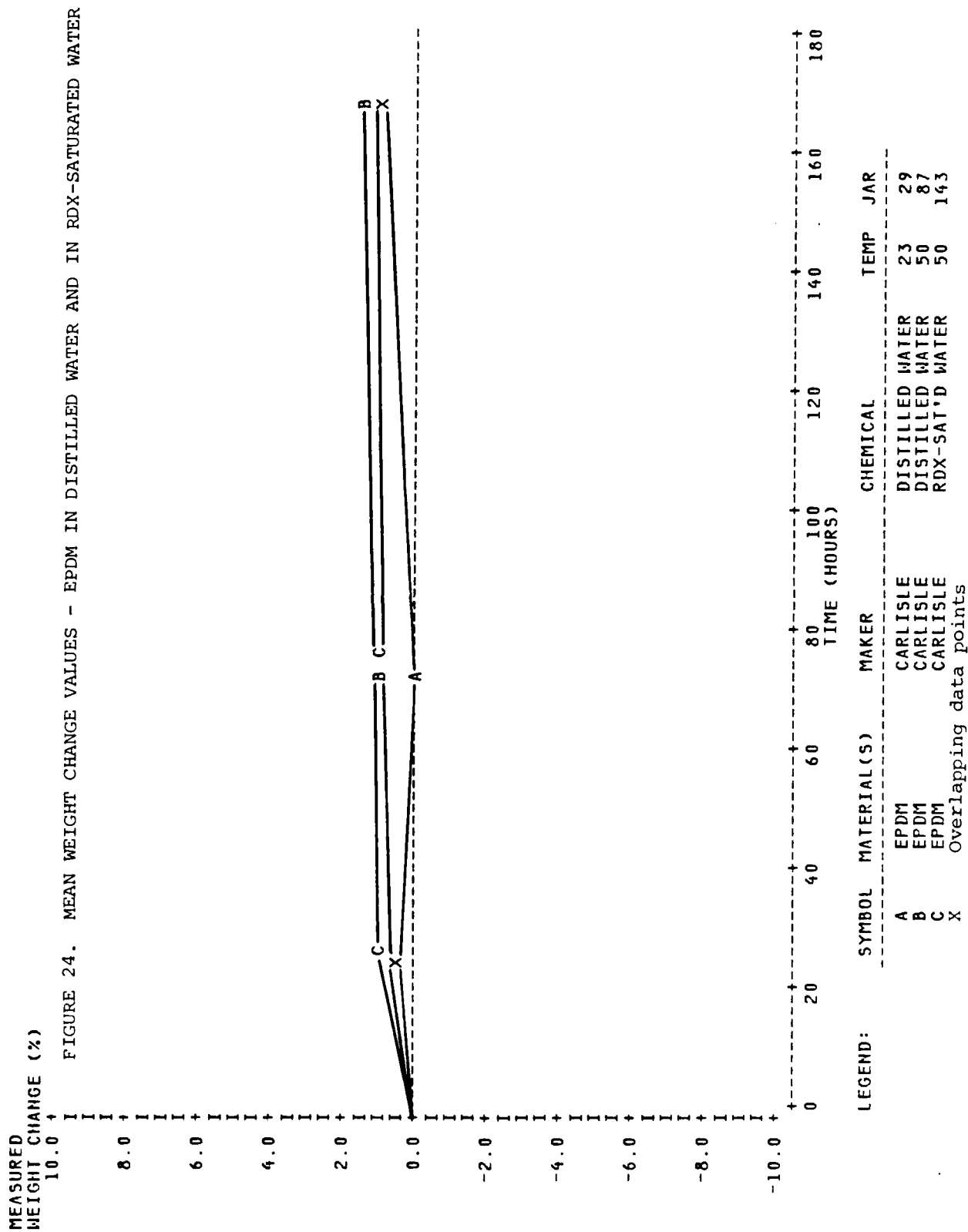


LEGEND:	SYMBOL	MATERIAL(S)	MAKER	CHEMICAL	TEMP	JAR
	A	HYPALON	STEVENS	DISTILLED WATER	23	17
	B	HYPALON	STEVENS	DISTILLED WATER	50	71
	C	HYPALON	STEVENS	RDX-SAT'D WATER	50	139
	X	Overlapping data points				



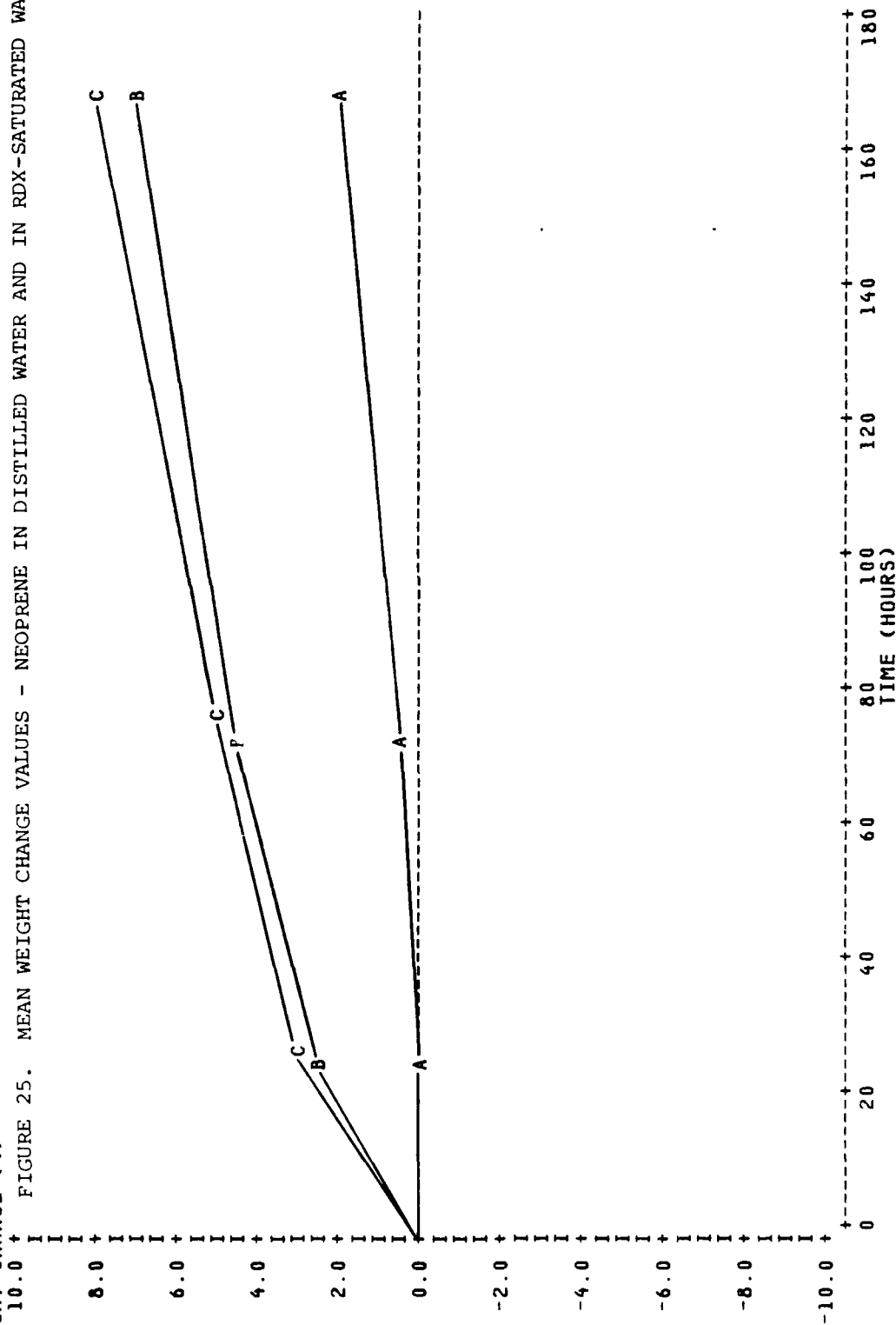






MEASURED
WEIGHT CHANGE (%)

FIGURE 25. MEAN WEIGHT CHANGE VALUES - NEOPRENE IN DISTILLED WATER AND IN RDX-SATURATED WATER



LEGEND:

SYMBOL	MATERIAL(S)	MAKER	CHEMICAL	TEMP	JAR
A	NEOPRENE	CARLISLE	DISTILLED WATER	23	32
B	NEOPRENE	CARLISLE	DISTILLED WATER	50	91
C	NEOPRENE	CARLISLE	RDX-SAT'D WATER	50	144

TABLE 15. PERCENT WEIGHT CHANGE AFTER 7-DAY IMMERSION
FOLLOWED BY 7-DAY DRYING

LINER GROUP/LINERS	CONTROL	IMMERSION SOLUTION	
	Unexposed 23°C	Distilled Water 23°C	Difference from Control
<u>PVC's</u>	-2.43 (1.09) ^a n=12 ^c	-2.96 (1.70) n=12	-0.53 (1.43) ^b
PVC (Palco)			
PVC (Pantasote)			
PVC-OR (Palco)			
PVC-OR (Pantasote)			
<u>CPE's/HYPALONS</u>	-0.34 (0.36) n=12	-0.40 (0.50) n=12	-0.06 (0.44)
CPE (Palco)			
CPE (Pantasote)			
Hypalon (Stevens)			
Hypalon (Pantasote)			
<u>HDPE</u>	-0.01 (0.04) n=3	-0.05 (0.08) n=3	-0.04 (0.06)
(Schlegel)			
<u>XR-5</u>	-0.47 (0.06) n=3	-0.88 (0.68) n=3	-0.41 (0.48)
(Shelter-Rite)			
<u>EPDM/NEOPRENE</u>	-0.48 (0.18) n=6	-0.18 (0.12) n=6	0.30 (0.15)
EPDM (Carlisle)			
Neoprene (Carlisle)			

^a Values in parentheses for immersion solutions are the standard deviations of the samples

^b Values in parentheses for the difference from control are the pooled standard deviations of the control samples and the immersion solution samples

^c n = Population size

TABLE 16. PERCENT ABSORBANCE AFTER 7-DAY IMMERSION

LINER GROUP/LINERS	CONTROL	IMMERSION SOLUTION	
	Unexposed 23°C	Distilled Water 23°C	Difference from Control
<u>PVC's</u>	1.20 (0.69) ^a n=12 ^c	1.44 (0.42) n=12	0.24 (0.57) ^b
PVC (Palco)			
PVC (Pantasote)			
PVC-OR (Palco)			
PVC-OR (Pantasote)			
<u>CPE's/HYPALONS</u>	0.17 (0.25) n=12	1.24 (0.88) n=12	1.07 (0.65)
CPE (Palco)			
CPE (Pantasote)			
Hypalon (Stevens)			
Hypalon (Pantasote)			
<u>HDPE</u>	0.21 (0.22) n=3	0.30 (0.16) n=3	0.09 (0.19)
(Schlegel)			
<u>XR-5</u>	0.13 (0.14) n=3	0.93 (0.10) n=3	0.80 (0.12)
(Shelter-Rite)			
<u>EPDM/NEOPRENE</u>	0.02 (0.06) n=6	1.49 (0.65) n=6	1.47 (0.46)
EPDM (Carlisle)			
Neoprene (Carlisle)			

^a Values in parentheses for immersion solutions are the standard deviations of the samples

^b Values in parentheses for the difference from control are the pooled standard deviations of the control samples and the immersion solution samples

^c n = Population size

TABLE 17. PERCENT WEIGHT CHANGE AFTER 7-DAY IMMERSION
FOLLOWED BY 7-DAY DRYING

LINER GROUP/LINERS	CONTROL	IMMERSION SOLUTION	
	Unexposed 50°C	Distilled Water 50°C	Difference from Control
<u>PVC's</u>	-1.88 (0.38) ^a n=12 ^c	-1.73 (0.57) n=12	0.15 (0.48) ^b
PVC (Palco)			
PVC (Pantasote)			
PVC-OR (Palco)			
PVC-OR (Pantasote)			
<u>CPE's</u>	-0.79 (0.10) n=6	-0.02 (0.71) n=6	0.77 (0.51)
CPE (Palco)			
CPE (Pantasote)			
<u>HYPALONS</u>	-0.09 (0.25) n=6	-0.14 (0.17) n=6	0.23 (0.21)
Hypalon (Stevens)			
Hypalon (Pantasote)			
<u>HDPE</u>	0.32 (0.11) n=2	0.30 (0.11) n=3	-0.02 (0.11)
(Schlegel)			
<u>XR-5</u>	-0.12 (0.23) n=3	-0.45 (0.24) n=3	-0.33 (0.24)
(Shelter-Rite)			
<u>EPDM/NEOPRENE</u>	-0.33 (0.22) n=6	0.25 (0.35) n=6	0.58 (0.29)
EPDM (Carlisle)			
Neoprene (Carlisle)			

^a Values in parentheses for immersion solutions are the standard deviations of the samples

^b Values in parentheses for the difference from control are the pooled standard deviations of the control samples and the immersion solution samples

^c n = Population size

TABLE 18. PERCENT ABSORBANCE AFTER 7-DAY IMMERSION

LINER GROUP/LINERS	CONTROL	IMMERSION SOLUTION	
	Unexposed 50°C	Distilled Water 50°C	Difference from Control
<u>PVC's</u>	-0.04 (0.86) ^a n=12 ^c	1.21 (1.19) n=12	1.25 (1.04) ^b
PVC (Palco)			
PVC (Pantasote)			
PVC-OR (Palco)			
PVC-OR (Pantasote)			
<u>CPE's</u>	-0.25 (0.18) n=6	4.54 (0.96) n=6	4.79 (0.69)
CPE (Palco)			
CPE (Pantasote)			
<u>HYPALONS</u>	-0.18 (0.12) n=6	1.57 (1.20) n=6	1.75 (0.85)
Hypalon (Stevens)			
Hypalon (Pantasote)			
<u>HDPE</u>	-0.37 (0.13) n=2	-0.10 (0.06) n=3	0.27 (0.09)
(Schlegel)			
<u>XR-5</u>	-0.14 (0.21) n=3	2.19 (0.17) n=3	2.33 (0.19)
(Shelter-Rite)			
<u>EPDM/NEOPRENE</u>	-0.14 (0.16) n=6	3.86 (2.82) n=6	4.00 (2.00)
EPDM (Carlisle)			
Neoprene (Carlisle)			

^a Values in parentheses for immersion solutions are the standard deviations of the samples

^b Values in parentheses for the difference from control are the pooled standard deviations of the control samples and the immersion solution samples

^c n = Population size

Of the other groups, Hypalon, XR-5 and EPDM showed gains of two to four percent. While these changes are viewed as minimal the distilled water results were used as the control for the test solution immersions.

Distilled Water (23°C)/Distilled Water (50°C)

A comparison of the dried weight change between samples immersed in distilled water at 23°C and 50°C is presented in Table 19. There was no significant difference between the percent dried weight change for any of the liner groups immersed in distilled water at 23°C and those immersed at 50°C. Elevation of the temperature has no significant effect on the dried weight for any of the samples in distilled water.

A comparison of the absorbance change between samples immersed in distilled water at 23°C and 50°C is presented in Table 20. The only liner group that showed an increased absorbance at the elevated temperature was the CPE with an increased absorbance of 3.3 percent. There was no significant increase for any of the other groups. The effect of elevated temperature on absorbance thus appears to be limited.

Distilled Water (23°C)/TCE-Saturated Water (23°C)

A comparison of dried weight changes between samples immersed in distilled water (control) and TCE-saturated water at 23°C is presented in Table 21. Only the CPE (Pantasote) was affected by the TCE-saturated water (a weight gain of 1.33 percent) compared to the distilled water control at 23°C. The weight increases for TCE-saturated water in the other groups were all less than one percent.

The absorbance difference between samples immersed in distilled water (control) and TCE saturated water at 23°C is compared in Table 22. The CPE (Pantasote) showed the largest increase; the difference in absorbance was almost 14 percent and is attributed to the TCE in the solution. The other liner groups showed absorbance increases of two to four percent. The significance of these increases is unknown. It was assumed that an increase of nearly 14 percent would be detrimental to the performance of the liner whereas the smaller increases (less than 5 percent) would have a lesser effect on performance.

In any case, it is likely that if a liner absorbs TCE it probably will desorb TCE from the other side due to concentration gradients. Thus, the measured absorbance may indicate the permeability of the liners to TCE.

Distilled Water (23°C)/Water-Saturated TCE (23°C)

A comparison of weight changes between samples immersed in distilled water (control) and water-saturated TCE at 23°C is also presented in Table 21. A water-saturated TCE solution is very concentrated with respect to TCE. The water-saturated TCE solutions had a

TABLE 19. PERCENT WEIGHT CHANGE AFTER 7-DAY IMMERSION
FOLLOWED BY 7-DAY DRYING

LINER GROUP/LINERS	CONTROL	IMMERSION SOLUTION	
	Distilled Water 23°C	Distilled Water 50°C	Difference from Control
<u>PVC's</u>	-2.96 (1.70) ^a n=12 ^c	-1.73 (0.57) n=12	1.23 (1.27) ^b
PVC (Palco)			
PVC (Pantasote)			
PVC-OR (Palco)			
PVC-OR (Pantasote)			
<u>CPE's/HYPALONS</u>			
CPE (Palco)		-0.02 (0.71)	0.38 (0.57)
CPE (Pantasote)		n=6	
	-0.40 (0.50) n=12		
Hypalon (Stevens)		-0.14 (0.17)	0.26 (0.43)
Hypalon (Pantasote)		n=6	
<u>HDPE</u>	-0.05 (0.08) n=3	0.30 (0.11) n=3	0.35 (0.10)
(Schlegel)			
<u>XR-5</u>	-0.88 (0.68) n=3	-0.45 (0.24) n=3	0.43 (0.51)
(Shelter-Rite)			
<u>EPDM/NEOPRENE</u>	-0.18 (0.12) n=6	0.25 (0.35) n=6	0.43 (0.26)
EPDM (Carlisle)			
Neoprene (Carlisle)			

^a Values in parentheses for immersion solutions are the standard deviations of the samples

^b Values in parenthesis for the difference from control are the pooled standard deviations of the control samples and the immersion solution samples

^c n = Population size

TABLE 20. PERCENT ABSORBANCE AFTER 7-DAY IMMERSION

LINER GROUP/LINERS	CONTROL	IMMERSION SOLUTION	
	Distilled Water 23°C	Distilled Water 50°C	Difference from Control
<u>PVC's</u>	1.44 (0.42) ^a n=12 ^c	1.21 (1.19) n=12	-0.23 (0.89) ^b
PVC (Palco)			
PVC (Pantasote)			
PVC-OR (Palco)			
PVC-OR (Pantasote)			
<u>CPE's/HYPALONS</u>			
CPE (Palco)		4.54 (0.96)	3.30 (0.91)
CPE (Pantasote)		n=6	
	1.24 (0.88)		
Hypalon (Stevens)	n=12	1.57 (1.20)	0.33 (0.99)
Hypalon (Pantasote)		n=6	
<u>HDPE</u>	0.30 (0.16)	-0.10 (0.06)	-0.40 (0.12)
(Schlegel)	n=3	n=3	
<u>XR-5</u>	0.93 (0.10)	2.19 (0.17)	1.26 (0.14)
(Shelter-Rite)	n=3	n=3	
<u>EPDM/NEOPRENE</u>	1.49 (0.65)	3.86 (2.82)	2.37 (2.05)
	n=6	n=6	
EPDM (Carlisle)			
Neoprene (Carlisle)			

^a Values in parentheses for immersion solutions are the standard deviations of the samples

^b Values in parentheses for the difference from control are the pooled standard deviations of the control samples and the immersion solution samples

^c n = Population size

TABLE 21. PERCENT WEIGHT CHANGE AFTER 7-DAY IMMERSION FOLLOWED BY 7-DAY DRYING

LINER GROUP/LINERS	CONTROL	IMMERSION SOLUTIONS			
	Distilled Water 23°C	TCE Sat'd Water 23°C	Difference from Control	Water Sat'd TCE 23°C	Difference from Control
<u>PVC's</u>					
PVC (Palco)	-2.96 (1.70) ^a n=12 ^c	-2.18 (0.87) n=12	0.78 (1.35) ^b	-22.56 (2.01) n=12	-19.60 (1.86)
PVC (Pantasote)					
PVC-OR (Palco)					
PVC-OR (Pantasote)					
<u>CPE's/HYPALONS</u>					
CPE (Palco)		-0.50 (0.84) n=9	0.10 (0.66)	d	
Hypalon (Stevens)					
Hypalon (Pantasote)	-0.40 (0.50) n=12	0.93 (0.23) n=3	1.33 (0.47)	d	
CPE (Pantasote)					
HDPE	-0.05 (0.08) n=3	0.44 (0.13) n=3	0.49 (0.11)	0.24 (0.03) n=3	0.29 (0.06)
(Schlegel)					
XR-5	-0.88 (0.68) n=3	-0.19 (0.57) n=3	0.69 (0.63)	-25.15 (0.55) n=3	-24.27 (0.62)
(Shelter-Rite)					
EPDM/NEOPRENE					
EPDM (Carlisle)	-0.18 (0.12) n=6	-0.17 (0.19) n=6	0.01 (0.16)	-15.88 (5.21) n=6	-15.70 (3.69)
Neoprene (Carlisle)					

^a Values in parentheses for immersion solutions are the standard deviations of the samples

^b Values in parentheses for the difference from control are the pooled standard deviations of the control samples and the immersion solution samples

^c n = Population size

^d Specimen dissolved in immersion solution

drastic effect on all the liner groups studied. This effect is reflected by the measured weight changes for all the liner groups with the exception of HDPE. After drying, the HDPE returned to near its pre-immersion weight with the difference between the distilled water control and the immersion solution samples being negligible (0.3 percent). However, a component of the HDPE did dissolve into the water-saturated TCE, tinting the solution orange.

The other liner groups either dissolved (CPE-Pantasote and CPE/Hypalon) or showed large weight losses. The weight losses for the PVC, XR-5 and EPDM/Neoprene groups were about 20, 24 and 16 percent respectively. The samples were brittle and stiff after drying. The large weight loss was assumed to be due to the soluble components in the samples being removed by the TCE. The stiffening indicates that plasticizers were removed.

A comparison of the absorbances for samples immersed in the distilled water control and water saturated TCE solutions at 23°C is presented in Table 22. As previously noted, the samples in the CPE (Pantasote) and CPE/Hypalon groups dissolved within 24 hours.

Three of the other liner groups (PVC, XR-5 and EPDM/Neoprene) showed extremely large absorbance gains in comparison to those for the distilled water immersions. These increases in percent absorbance were 51 percent for PVC, 213 percent for XR-5 and 155 percent for EPDM/ Neoprene; all attributable to the TCE.

These liners readily absorbed TCE at the high TCE concentrations. Absorbance to this extent clearly indicates an incompatibility of the material with the solution. Additionally, the liners swelled to a large degree during the immersion. Once swollen, the liners softened and apparently lost much of their structural strength. Moreover, these changes took place rapidly, within 24 hours.

The HDPE also exhibited an increase in absorbance (about 14 percent). The HDPE softened noticeably and became much more flexible during the immersion. The samples also appeared to lose some of their structural strength. Finally, the water saturated TCE solution turned orange indicating the loss of soluble constituents from the samples. As previously discussed, the absorbance parameter may be an indication of permeability. The high absorbance of the HDPE samples may indicate that it, too, is permeable to TCE at high concentrations.

Distilled Water (50°C)/TCE-Saturated Water (50°C)

A comparison of dried weight changes for samples immersed in the distilled water control and TCE-saturated water at 50°C is presented in Table 23. The liners immersed in TCE-saturated water at 50°C showed no significant difference in weight change from those in the control solution for all liner groups.

TABLE 22. PERCENT ABSORBANCE AFTER 7-DAY IMMERSION

LINER GROUP/LINERS	IMMERSION SOLUTIONS				
	CONTROL				
	Distilled Water 23°C	TCE Sat'd Water 23°C	Difference from Control	Water Sat'd TCE 23°C	Difference from Control
PVC's	1.44 (0.42) ^a n=12 ^c	6.15 (1.38) n=12	4.71 (1.02) ^b	52.67 (5.89) n=12	51.23 (4.18)
PVC (Palco)					
PVC (Pantasote)					
PVC-OR (Palco)					
PVC-OR (Pantasote)					
CPE's/HYPALONS					
CPE (Palco)		4.14 (1.64) n=9	2.90 (1.26)	d	
Hypalon (Stevens)					
Hypalon (Pantasote)	1.24 (0.88) n=12				
CPE (Pantasote)		15.17 (0.18) n=3	13.93 (0.81)	d	
HDPE (Schlegel)	0.30 (0.16) n=3	2.52 (0.09) n=3	2.22 (0.13)	14.61 (0.32) n=3	14.31 (0.25)
XR-5 (Shelter-Rite)	0.93 (0.10) n=3	4.43 (0.04) n=3	3.50 (0.08)	213.57 (1.56) n=3	212.64 (1.11)
EPDM/NEOPRENE					
EPDM (Carlisle)	1.49 (0.65) n=6	6.26 (0.56) n=6	4.77 (0.61)	156.74 (14.57) n=6	155.25 (10.31)
Neoprene (Carlisle)					

^a Values in parentheses for immersion solutions are the standard deviations of the samples

^b Values in parentheses for the difference from control are the pooled standard deviations of the control samples and the immersion solution samples

^c n = Population size

^d Specimen dissolved in immersion solution

TABLE 23. PERCENT WEIGHT CHANGE AFTER 7-DAY IMMERSION FOLLOWED BY 7-DAY DRYING

LINER GROUP/LINERS	CONTROL		IMMERSION SOLUTIONS			
	Distilled Water 50°C	TCE Sat'd Water 50°C	Difference from Control	TNT Sat'd Water 50°C	Difference from Control	RDX Sat'd Water 50°C Difference from Control
<u>PVC's</u>						
PVC (Palco)	-1.73(0.57) ^a n=12 ^c	-1.53(0.85) n=12	0.20(0.72) ^b	0.66(0.25) n=12	2.39(0.44)	-5.23(1.34) n=12
PVC (Pantasote)						-3.5(1.03)
PVC-OR (Palco)						
PVC-OR (Pantasote)						
<u>CPE's</u>						
CPE (Palco)	-0.02 (0.71) n=6	1.60 (2.28) n=6	1.62 (1.68)	2.44 (0.71) n=6	2.46 (0.71)	-0.74(0.55) n=6
CPE (Pantasote)						-0.72(0.64)
<u>HYPALONS</u>						
Hypalon (Stevens)	-0.14 (0.17) n=6	-0.30 (0.39) n=6	0.16 (0.30)	0.75 (0.21) n=6	0.89 (0.19)	-0.57(0.02) n=3
Hypalon (Pantasote)						-0.22(0.15)
<u>HDPE</u>						
(Schlegel)	0.30 (0.11) n=3	0.46 (0.08) n=3	0.16 (0.27)	0.16 (0.15) n=3	-0.14 (0.20)	-0.19(0.04) n=3
<u>XR-5</u>						
(Shelter-Rite)	-0.45 (0.24) n=3	-0.74 (0.29) n=3	-0.29 (0.27)	1.06 (0.12) n=3	1.51 (0.19)	-1.4(0.08) n=3
<u>EPDM/NEOPRENE</u>						
EPDM (Carlisle)	0.25 (0.35) n=6	0.71 (0.45) n=6	0.46 (0.40)	1.46 (0.94) n=6	1.21 (0.71)	-0.5(0.11) n=3
Neoprene (Carlisle)						-0.30 (0.30)
						1.33(0.06) n=3
						0.96(0.30)

^a Values in parentheses for immersion solutions are the standard deviations of the samples^b Values in parentheses for the difference from control are the pooled standard deviations of the control samples and the immersion solution samples^c n = Population size

A comparison of the absorbances of samples immersed in the distilled water control and TCE-saturated water at 50°C is presented in Table 24. All the liner groups, except HDPE, showed moderate absorbance increases varying from five to nine percent in magnitude.

The CPE and Hypalon groups showed the largest increases (nine and seven percent) of the samples immersed in TCE-saturated water at 50°C as they also did for the 23°C immersions. The percent absorbance for TCE was slightly greater at the elevated temperature for all the groups except HDPE.

Distilled Water (50°C)/TNT-Saturated Water (50°C)

A comparison of the dried weight changes of samples immersed in the distilled water control and TNT-saturated water at 50°C is presented in Table 23. Three of the liner groups (PVC, CPE and XR-5) had small weight gains relative to the control immersions. A fourth liner group, EPDM/Neoprene, also exhibited a small weight gain, but the pooled standard deviation was of the same magnitude as the change. While the weight gains are apparently due to TNT entering the liner structure, they are minor and it is assumed that they would not impair the structural strength of the liner.

A comparison of the absorbance of samples immersed in the distilled water control and TNT-saturated water at 50°C is presented in Table 24. The liners immersed in TNT saturated water at 50°C showed no significant difference in absorbance compared to the control immersions. The apparent ability of TNT to enter the liner structure may however be a path way for TNT to pass through the membrane and out of the containment.

Distilled Water (50°C)/RDX-Saturated Water (50°C)

A comparison of the dried weight changes of samples immersed in the distilled water control and RDX-saturated water at 50°C is presented in Table 23. The PVC group was the only one to show a difference in weight change (3.5 percent) relative to the control.

The absorbance of samples immersed in the distilled water control and RDX-saturated water at 50°C is presented in Table 24. Three of the liner groups showed changes in absorbance in comparison to the distilled water control. The absorbance changes varied from -2.3 percent for EPDM to about three percent for PVC and Neoprene.

The change in absorbance for EPDM and Neoprene may be due to the variability of the data (a large pooled standard deviation), and thus there may be no definite difference from the control distilled water immersion. The PVC group does show an increase in absorbance; however, the increase (2.6 percent) is probably insignificant with respect to liner performance.

TABLE 24. PERCENT ABSORBANCE AFTER 7-DAY IMMERSION

LINER GROUP/LINERS	CONTROL		IMMERSION SOLUTIONS				
	Distilled water 50°C		TCE Sat'd water 50°C	Difference from Control	TNT Sat'd Water 50°C	Difference from Control	RDX Sat'd water 50°C Difference from Control
PVC's	1.21 (1.19) ^a	4.99(1.18)	3.1 (1.19) ^b	0.30 (1.24)	3.79 (0.88)	2.58 (1.05)	
PVC (Palco)	n=12 ^c	n=11	n=12		n=12		
PVC (Pantasote)							
PVC-OR (Palco)							
PVC-OR (Pantasote)							
CPE's							
CPE (Palco)	4.54 (0.96)	8.81 (1.40)	4.27 (1.20)	-0.13 (0.81)	5.79 (0.61)	1.25 (0.80)	
CPE (Pantasote)	n=6	n=6	n=6		n=6		
HYPALONS							
Hypalon (Stevens)	1.57 (1.20)	7.31 (0.55)	5.74 (0.93)	0.01 (1.13)	1.22 (0.02)	-0.35 (1.01)	
Hypalon (Pantasote)	n=6	n=6	n=6		n=3	1.36 (1.02)	
HDPE (Schlegel)	-0.10 (0.06)	0.60 (0.09)	0.70 (0.08)	0.11 (0.06)	0.26 (0.12)	0.36 (0.09)	
	n=3	n=3	n=3		n=3		
XR-5 (Shelter-Rite)	2.19 (0.17)	7.43 (0.17)	5.24 (0.17)	0.42 (0.18)	3.24 (0.25)	1.05 (0.21)	
	n=3	n=3	n=3		n=3		
EPDM/NEOPRENE							
EPDM (Carlisle)	3.86 (2.82)	9.19 (0.14)	5.33 (2.00)	0.42 (3.05)	1.53 (0.2)	-2.33 (2.39)	
Neoprene (Carlisle)	n=6	n=6	n=6		n=3	2.75 (2.38)	
					n=3		

^a Values in parentheses for immersion solutions are the standard deviations of the samples^b Values in parentheses for the difference from control are the pooled standard deviations of the control samples and the immersion solution samples^c n = Population size

LINER COMPATIBILITY

A projection of the potential compatibility of the five liner groups (PVC, CPE/Hypalon, XR-5, HDPE and EPDM/Neoprene) based on previously discussed results is presented in Table 25. The values in Table 25 are an assessment of the effect of the test chemicals on each liner based on the results of the screening test. A rating of one is used to indicate minimal effect and a rating of five to indicate failure of the liner.

HDPE appears to be potentially compatible with TNT and RDX, and may be compatible with TCE. The other four liner groups also appear to be potentially compatible with TNT and RDX; however, all four groups were found to be incompatible with TCE.

TABLE 25. SUMMARY OF THE INITIAL SCREENING TEST RESULTS

Liner Group	<u>Relative Effect of Test Chemical¹</u>		
	TCE	TNT	RDX
PVC	4	3	3
CPE/Hypalon	5	3	2
XR-5	5	2	2
HDPE	3	1	1
EPDM/Neoprene	4	2	2

¹ Relative effects are ranked from 1 (minimal) to 5 (failure).

CHAPTER 6

CONCLUSIONS AND SUMMARY

CONCLUSIONS

The following conclusions were made based on the observations of the test results.

Test Methodology

- o The initial screening test step of the Proposed NSF Test Protocol proved to be easy to use and repeatable; however, before it could be used it was necessary to establish specific testing procedures.
- o The weight change and absorbance measurements were very reproducible and provide consistent response patterns.
- o The volume change and swell measurements were much less reproducible than the weight change measurements and did not provide consistent response patterns. These problems were attributed to inherent difficulties with the measurement procedures.
- o The data generated by the screening test of the Proposed NSF Test Protocol provide a basis for preliminary evaluation of liner compatibility; however, because there are no established evaluation criteria, data interpretation is in part subjective and requires a careful analysis and comparison of the data.

Temperature Effects

- o Temperature had a minor effect on liner sample weight changes during immersion except for CPE (Pantasote) and EPDM and Neoprene (both Carlisle); each had about a four percent weight increase at 50°C (compared to 23°C).
- o Temperature had no effect on the dried weight change of any of the liner samples.
- o Temperature had little effect (less than 2 percent) on liner absorbance in distilled water.
- o The only temperature effect noted in the test chemical solutions was a minimal increase in absorbance at 50°C (compared to 23°C) for samples immersed in the TCE-saturated water.

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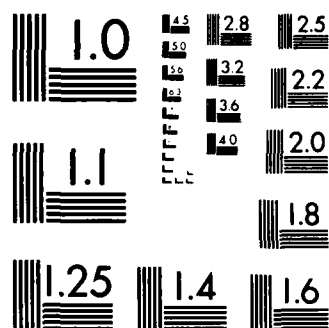
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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TCE-Saturated Water

- o The only visual change noted for liners immersed in TCE saturated water was swelling at the bottom of the liner samples of CPE (Pantasote) and Hypalon (Stevens).
- o All the liner groups showed an increase in measured weight during immersion. The weight increases during immersion were rapid, occurring within 24 hours.
- o The largest weight increases measured during immersion were with the CPE and Hypalon samples which increased 10 and 15 percent respectively.
- o There was no significant dried weight change for any of the liners in the TCE-saturated water immersion at either 23°C and 50°C relative to the distilled water control.
- o Liner absorbance increased for both the 23°C and 50°C TCE-saturated water immersions. The largest increase was for CPE (Pantasote) where absorbance increased by nine percent from the distilled water control.

Water-Saturated TCE

- o The CPE and Hypalon samples dissolved within 24 hours.
- o All the liner samples showed drastic and rapid (within 24-hours) visual changes during immersion. The visual changes included swelling and ply separation. Additionally, after drying the liner samples shrank and stiffened.
- o Visually, HDPE was the least affected liner.
- o All of the liner groups showed significant and rapid (within 24-hours) weight increases during immersion. The weight increase for some liners was over 140 percent.
- o The PVC, XR-5 and EPDM/Neoprene liner samples had extreme dried weight losses (minus 20, minus 24 and minus 16 percent, respectively). These weight losses were probably due to removal of soluble constituents such as plasticizers from the liner samples.
- o The HDPE samples showed no dried weight loss.
- o The PVC's, XR-5 and EPDM/Neoprene liner samples had extreme absorbance increases (51, 213 and 155 percent, respectively).
- o HDPE had the smallest absorbance increase: 14 percent.

TNT-Saturated Water

- o There was little visual change for any of the liner samples immersed in TNT.
- o All of the liner groups except HDPE showed an increase in weight during the TNT-saturated water immersions.
- o The weight gains for the liners immersed in TNT-saturated water, except HDPE, were still increasing at the end of seven days of immersion.
- o All of the liner groups, except HDPE, had a residual weight gain of between five and nine percent after the 7-day drying period.
- o There was no significant increase in absorbance for any of the liner groups.

RDX-Saturated Water

- o Visual changes associated with immersion in RDX were limited to a slight softening and curl of the PVC samples, slight softening of the Palco PVC-OR and CPE samples and the surface of the two Hypalons and the XR-5 samples becoming tacky.
- o Only the PVC and Neoprene liner samples showed an increase in weight during the RDX-saturated water immersion.
- o The weight increases were less than one percent for all the liner samples; however, liner weights were still increasing at the end of the 7-day immersion period.
- o The PVC liner samples had an average weight loss of four percent after drying.
- o There were slight increases in absorbance for the PVC (three percent) and the Neoprene (three percent) liner samples although the increase in absorbance in the Neoprene samples may have been due to sample deviation.
- o The EPDM samples had an absorbance loss of three percent; however, this loss may have been due to sample deviation.

SUMMARY

HDPE appears to be potentially compatible with TNT and RDX, and may be compatible with TCE. The other four liner groups also appear to be potentially compatible with TNT and RDX; however, all four groups were found to be incompatible with TCE.

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APPENDIX A

LINER MANUFACTURING SURVEY DATA

INDEX

Carlisle Tire & Rubber Company
Dow Chemical USA
duPont Company
General Tire Plastic and Film Company
B. F. Goodrich
Gundle Lining Systems, Inc.
Hercules, Inc.
Mainline
Palco Linings, Inc.
Pantasote, Inc.
Schelgel Lining Technology, Inc.
Shelter-Rite
Staff Industries, Inc.
Stevens Elastomeric & Plastic Products, Inc.
Watersaver Company, Inc.

Carlisle

I. COMPANY

Carlisle Tire & Rubber Company
Division of Carlisle Corporation

Bill Witherow 249-1000
Product Manager
Construction Materials Division
P. O. Box 99
Carlisle, Pennsylvania 17013

II. CLASSIFICATION

Roll good producer, sheet fabricator

III. PRODUCTS

Type	Stock Supplier	Reinf. ¹	Seams		Thickness (mil)	Width
			Factory	Field ²		
Butyl	Proprietary	U	vulcanized	adhesive	30, 60, 90, 120	50 ft (10 ft to seams)
		S	vulcanized	adhesive	30, 60, 90, 120	50 ft (10 ft to seams)
EPDM	Proprietary	U	vulcanized	adhesive	30, 45, 60, 90, 120	50 ft (10 ft to seams)
		S	vulcanized	adhesive	30, 45, 60, 90, 120	50 ft (10 ft to seams)
Neoprene	duPont	U	vulcanized	adhesive	30, 60, 90, 120	50 ft (10 ft to seams)
		S	vulcanized	adhesive	30, 60, 90, 120	50 ft (10 ft to seams)

¹ U - Unsupported

S - Supported

² Recommended

IV. COMPATIBILITY

A. Compatibility data
Yes, see Appendix B

B. Compatibility testing
Immersion

C. Liner recommendations
TNT - unknown
RDX - unknown
TCE - unknown

D. Existing hazardous waste installations list
Yes, see Appendix C

DOW

I. COMPANY

Dow Chemical USA

Lynne A. Hanrahan 504/389-8275
Senior Research Engineer
CPE Industrial Products

Designed Products Department
P. O. Box 150 - Building 2307
Plaquemine, Louisiana 70764

II. CLASSIFICATION

Resin manufacturer

III. PRODUCT

CPE resin

IV. COMPATIBILITY

- A. Compatibility data
Yes, see Appendix B
- B. Compatibility testing
Immersion
- C. Liner recommendations
TNT - unknown
RDX - unknown
TCE - not recommended

V. ROLL GOOD PRODUCERS USING DOW RESIN

B. F. Goodrich
Mainline Company
Pantasote Company
Stevens

duPont

I. COMPANY

duPont Company 302/998-4855
Elastomers Inquiry Center
Elastomers Laboratory
Chesnut Run
Wilmington, Delaware 19898

II. CLASSIFICATION

Resin producer

III. PRODUCTS

Hypalon resin
Neoprene resin
Nordell resin (hydrocarbon rubber)

IV. COMPATIBILITY TESTING

- A. Compatibility data
Yes, see Appendix B
- B. Compatibility testing
Immersion
- C. Liner recommendation
Unavailable

V. ROLL GOOD PRODUCERS USING DU PONT RESIN

Burke Industries
Carlisle
Cooley Corporation
Dunlop Industrial
B. F. Goodrich
Stevens

General Tire

I. COMPANY

General Tire Plastic and Film Company

Joel Kaster 614/498-5900
(Ed Chambers)
Newcomerstown, Ohio 43832

II. CLASSIFICATION

Roll good producer

III. PRODUCTS

Type	Stock Supplier	Reinf. ¹	Seams		Thickness (mil)	Width
			Factory ²	Field ²		
PVC		U			15 and up	
HDPE	USI, Soltex	U	heat weld	heat weld	40 and up	4 ft x 8 ft panels
Polypropylene	Hercules, Nova Mont Division of U. S. Steel	U	heat weld	heat weld	60 and up	4 ft x 8 ft panels

¹ U - Unsupported

S - Supported

² Recommended

IV. COMPATIBILITY

- A. Compatability data
Yes, see Appendix B
- B. Compatibility testing
Immersion
- C. Liner recommendations
TNT - unknown
RDX - unknown
TCE - none recommended
- D. Existing hazardous waste installations list
None available

B. F. Goodrich

I. COMPANY

B. F. Goodrich

Dick Cunningham 216/374-2226
Marketing Manager
Environmental Products
500 South Main Street
Akron, Ohio 44108

II. CLASSIFICATION

Resin manufacturer, roll good producer, sheet fabricator,
installer

III. PRODUCTS

Type	Stock Supplier	Reinf. ¹	Seams		Thickness (mil)	Width
			Factory ²	Field		
PVC	B. F. Goodrich	U	dielectric	solvent	10, 15, 20,	100 ft ³
			heat	weld	30	(72 in. to seams)
PVC-OR	B. F. Goodrich	U	dielectric	solvent	30	100 ft ³
			heat	weld		(72 in. to seams)
Hypalon	duPont	S	dielectric	solvent	36, 45	100 ft. ³
			heat	weld		(60 in. to seams)
CPE	Dow	U	dielectric	solvent	30	100 ft ³
			heat	weld		(72 in. to seams)
		S	dielectric	solvent	36, 45	100 ft ³
			heat	weld		(60 in. to seams)
EPDM		U	dielectric	solvent	30	100 ft ³
			heat	weld		(72 in. to seams)
		S	dielectric	solvent	36, 45	100 ft ³
			heat	weld		(60 in. to seams)

¹ U - Unsupported

S - Supported

² B. F. Goodrich seam, subcontractors (Staff, etc.) use solvent welds

³ Normal maximum, width can be greater as long as total weight is under 5,000 lbs

IV. COMPATIBILITY

A. Compatibility data
Not available

B. Compatibility testing
Immersion

B. F. Goodrich
(continued)

- C. Liner recommendations
 - TNT - unknown
 - RDX - unknown
 - TCE - none of the above liners are recommended for appreciable concentrations, possibly Shelter-Rite® XR-5 or HDPE
- D. Existing hazardous waste installations list
 - Yes, see Appendix C

Gundle

I. COMPANY

Gundle Lining Systems, Inc.

Jim Kimbell 404/491-8644
Southern Regional Manager
3343 Northcrest
Atlanta, Georgia 30340

(Home office)
Gundle Road
1340 East Richey
Houston, Texas 77073

II. CLASSIFICATION

Roll good sheet producer (no fabrication), installer

III. PRODUCT

Type	Stock Supplier	Reinf. ¹	Seams		Thickness (mil)	Width
			Factory	Field		
HDPE	Phillips	U	N/A	dynamic extrudate weld	20, 30, 40, 50, 60, 80, 100	22-1/2 ft
HDA (high density alloy w/ butadiene rubber)	Phillips	U	N/A	dynamic extrudate weld	20, 30, 40, 50, 60, 80, 100	22-1/2 ft

- ¹ U - Unsupported
S - Supported

IV. COMPATIBILITY

- A. Compatibility data
Yes, see Appendix B
- B. Compatibility testing
Immersion
- C. Liner recommendations
TNT - unknown
RDX - unknown
TCE - unknown
- D. Existing hazardous waste installations list
Not available

Hercules

I. COMPANY

Hercules, Inc.

Sam McEllroy 302/575-5730
910 Market Street
Wilmington, Delaware 19899

II. CLASSIFICATION

Resin manufacturer

III. PRODUCTS

Polypropylene resin

IV. COMPATIBILITY

A. Compatibility data
Yes, see Appendix B

B. Compatibility testing
Immersion

C. Liner recommendations
TNT - probably polypropylene and polyethylene would work
RDX - unknown
TCE - unknown

V. ROLL GOOD PRODUCERS USING HERCULES RESIN

Shenandoah Plastics
Westlake Plastics
Polyhi-Scranton
General Tire & Rubber Co.

Mainline

I. COMPANY

Mainline

Keith Main 503/548-4027
Production Manager
3292 South Highway 97
Redman, Oregon 97756

II. CLASSIFICATION

Roll good producer

III. PRODUCTS

Type	Stock Supplier	Reinf. ¹	Seams		Thickness (mil)	Width
			Factory ²	Field ²		
PVC	B. F. Goodrich	U	dielectric weld	solvent weld	20	57 in.
		S	dielectric weld	solvent weld	30, 45	54 in.
PVC-OR	B. F. Goodrich	U	dielectric weld	solvent weld	30	55-1/2 in.
		U	dielectric weld	solvent weld	30	54 in.
CPE	Dow	U	dielectric weld	adhesive	20	57 in.
		S	dielectric weld	adhesive	30, 45	54 in.
			dielectric weld	adhesive	36, 45	55-1/2 in.

¹ U - Unsupported

S - Supported

² Recommended

IV. COMPATIBILITY

A. Compatibility data
None available

B. Compatibility testing
Immersion

C. Liner recommendation
TNT - unknown
RDX - unknown
TCE - unknown

D. Existing hazardous waste installation list
None available

Palco

I. COMPANY

Palco Linings, Inc.

Michael J. Del Monaco
Sales Engineer
7571 Santa Rita Circle
Stanton, California 90680

714/898-0867

II. CLASSIFICATION

Sheet fabricator

III. PRODUCTS

Type	Stock Supplier	Reinf. ¹	Seams		Thickness (mil)	Width
			Factory	Field ²		
CPE alloy (Dynalloy)	Mainline Fabricators	U	dielectric weld	adhesive	20, 30	max 100 ft (54 in. to seams)
		S	dielectric weld	adhesive	36, 45	max 100 ft (55-1/2 in. to seams)
PVC	Mainline Fabricators	U	dielectric weld	solvent weld	20, 30	max 100 ft (54 in. to seams)
		S	dielectric weld	solvent weld	36	max 100 ft (54 in. to seams)
PVC- OR	Mainline Fabricators	U	dielectric weld	solvent weld	30	max 100 ft (54 in. to seams)

¹ U - Unsupported

S - Supported

² Recommended

IV. COMPATIBILITY

A. Compatibility data
None available

B. Compatibility testing
Immersion tests

C. Liner recommendations
TNT - unknown
RDX - unknown
TCE - unknown

D. Existing hazardous waste installations list
Yes, see Appendix C

Pantasote

I. COMPANY

Pantasote, Inc.
Film/Compound Division

Larry Kamp 201/777-8500
36 Jefferson Street
Passaic, New Jersey 07055

II. CLASSIFICATION

Roll good producer, resin producer for PVC

III. PRODUCTS

Type	Stock Supplier	Reinf. ¹	Seams		Thickness (mil)	Width
			Factory ²	Field ²		
CPE	Dow	U	heat, solvent, dielectric	adhesive	20, 30	76 in
		S	heat, solvent, dielectric	solvent, weld, adhesive	36, 45	72 in
PVC	Pantasote	U	heat, solvent, dielectric	adhesive	20, 30	86 in 80 in
PVC-OR	Pantasote	U	heat, solvent, dielectric	adhesive	30	80 in
Hypalon	duPont	S	heat, solvent, dielectric	adhesive	36, 45	60 in

¹ U - Unsupported

S - Supported

² Recommended

IV. COMPATIBILITY

A. Compatibility data
Yes, see Appendix B

B. Compatibility testing
Immersion
Simulation (sun lamps)

Pantasote
(continued)

- C. Liner recommendations
 - TNT - unknown
 - RDX - unknown
 - TCE - no known liner, maybe HDPE
- D. Existing hazardous waste installations list
 - Yes, see Appendix C

Schlegel

I. COMPANY

Schlegel Lining Technology, Inc.

John VanderVoort 800/231-1298
Technical Director
(Chuck Crisman)

200 South Trade Center Parkway
P. O. Box 7730
The Woodlands, Texas 77380

II. CLASSIFICATION

Resin producer, roll good sheet producer (no fabrication),
installer.

III. PRODUCT

Type	Stock Supplier	Reinf. ¹	Seams		Thickness (mil)	Width
			Factory	Field		
HDPE	Schlegel	U	N/A	Extrusion weld	60, 80, 100	34 ft

- ¹ U - Unsupported
S - Supported

IV. COMPATIBILITY

- A. Compatibility data
Yes, see Appendix B.
- B. Compatibility testing
Immersion
- C. Liner recommendations
TNT - unknown
RDX - unknown
TCE - HDPE
- D. Existing hazardous waste installations list
Yes, see Appendix C

Shelter-Rite

I. COMPANY

Shelter-Rite
Division of Seaman Corporation

Bala Venkataraman 216/674-2015
Vice President
Research and Development
P. O. Box 331
Millersburg, Ohio 44654

II. CLASSIFICATION

Roll good producer, sheet fabricator

III. PRODUCT

Type	Stock Supplier	Reinf. ¹	Seams		Thickness (mil)	Width
			Factory	Field ²		
ethylene inter- polymer alloy (ELPO alloy)	Hooker, Ferro	S	dielectric, thermal, thermal, welds welds		30	58 in.

¹ U - Unsupported

S - Supported

² Recommended

IV. COMPATIBILITY

A. Compatibility data

Yes, see Appendix B

B. Compatibility testing

Immersion

C. Liner recommendations

TNT - unknown

RDX - unknown

TCE - unknown

D. Existing hazardous waste installations list

None available

Staff

I. COMPANY

Staff Industries, Inc.

Dr. Charles Staff 800/526-1368
President
P. O. Box 759
Upper Montclair, New Jersey 07043

II. CLASSIFICATION

Sheet fabricator

III. PRODUCTS

Type	Stock Supplier	Reinf. ¹	Seams		Thickness (mil)	Width
			Factory	Field ²		
PVC	Pantasote	U	solvent weld	solvent weld	10, 15, 20	100 ft (5 ft to seams)
		S	solvent weld	solvent weld	32	82.8 ft (4.6 ft to seams)
PVC-OR	Pantasote	U	solvent weld	solvent weld	30	100 ft (5 ft to seams)
Hypalon (CSPE)	Stevens	S	solvent weld	solvent weld	36	82.8 ft (4.6 ft to seams)
CPE	Harte	U	solvent weld	solvent weld	30	100 ft (5 ft to seams)
		S	solvent weld	solvent weld	36	82.8 ft (4.6 ft to seams)

¹ U - Unsupported

S - Supported

² Recommended

IV. COMPATIBILITY

A. Compatibility data

Yes, see Appendix B

B. Compatibility testing

Use J. P. Stevens labs

C. Liner recommendations

TNT - unknown

RDX - unknown

TCE - maybe HDPE

D. Existing hazardous waste installation list

Yes, see Appendix C

Stevens

I. COMPANY

Stevens Elastomeric & Plastic Products, Inc.
Subsidiary of J. P. Stevens & Company, Inc.

Arnold Peterson 413/527-0700
Easthampton, Massachusetts 01027

II. CLASSIFICATION

Roll good producer

III. PRODUCTS

Type	Stock Supplier	Reinf. ¹	Seams		Thickness (mil)	Width
			Factory ²	Field ²		
Hypalon (CSPE)	duPont	S	dielectric solvent, heat weld	adhesive	36	58 in.

¹ U - Unsupported

S - Supported

² Recommended

IV. COMPATIBILITY

A. Compatibility data
Not available

B. Compatibility testing
Immersion
Simulation (sun lamps)

C. Liner recommendations
TNT - Neoprene (excellent), hypalon (good), butyl (poor),
EPDM (poor)
RDX - unknown
TCE - Hypalon (poor), (for appreciable concentrations)

D. Existing hazardous waste installations list
Not available

Watersaver

I. COMPANY

Watersaver Company, Inc.

Gary Markle 303/623-4111
Regional Manager
P. O. Box 16465
Denver, Colorado 80216

II. CLASSIFICATION

Sheet fabricator

III. PRODUCTS

Type	Stock Supplier	Reinf. ¹	Seams		Thickness (mil)	Width
			Factory	Field ²		
PVC	Harte	U	dielectric, solvent weld	solvent weld	10, 20, 30	70 ft (6.3 ft to seams)
Hypalon	Stevens (duPont) resin	S	dielectric, solvent weld	solvent weld	36	70 ft (4.75 ft to seams)
CPE	Stevens	U	dielectric, solvent weld	solvent weld	30	70 ft (4.75 ft to seams)
		S	dielectric, solvent weld	solvent weld	36	70 ft (4.75 ft to seams)
EPDM	Carlisle	U	dielectric, solvent weld	solvent weld	45	54 in.
		S	dielectric, solvent weld	solvent weld	60	54 in.

¹ U - Unsupported

 S - Supported

² Recommended

IV. COMPATIBILITY

A. Compatibility data
 Yes, see Appendix B

B. Compatibility testing
 Immersion

Watersaver
(continued)

- C. Liner recommendations
 - TNT - unknown
 - RDX - unknown
 - TCE - unknown

- D. Previous hazardous waste installations list
 - Yes, see Appendix C

APPENDIX B

NATIONAL SANITATION FOUNDATION STANDARD FOR FLEXIBLE MEMBRANES

(Appendix E - Recommended Test Method for Determining Long-Term
Performance of Liners in a Chemical Environment)

APPENDIX E

Recommended Test Method for Determining Long-Term Performance of Membrane Liners in a Chemical Environment

A. INTRODUCTION

These test methods are for the initial and long-term evaluation of flexible membrane liner materials intended to contain chemicals in a pit, pond, lagoon or landfill-type installation. The effects upon the physical properties of the liner materials will be determined. Data from these tests will assist in deciding whether a liner material should be used in a given chemical environment.

The test method is based upon ASTM D543 and ASTM D471 which specify the particular physical properties to be measured for plastics and rubber, respectively.

The scope of this appendix is to cover general test methods which may be of assistance in selecting a flexible membrane liner where other than fresh water is to be contained. Specific applications may require additional tests related to the particular environment. Some tests in this appendix may not be applicable to certain other applications. Some installations may not require long term evaluation testing per Appendix E if the manufacturer can provide similar test data and/or service experience for similar applications.

B. INITIAL EVALUATION

Specimens are exposed in the test environment for 1, 3 and 7 days at 23°C and 50°C. At least three specimens shall be used for each material being tested, at each temperature and for each chemical environment to be involved. Data on weight, dimensions and visual changes are obtained as described in Procedure I (Section I).

C. LONG-TERM EVALUATION

Sets of three test specimens are immersed in the chemical environment for each flexible membrane liner material being tested, at each temperature, and for each set of physical properties being tested. For example:

Property	No. of Specimens
Tensile, Modulus & Elongation	3
Weight & Dimensions	3
Ply Adhesion	3
Tear Test	3
Factory Seams	3
Visual	any/all of above samples

The weight and dimensional changes shall be determined after immersion in the chemical environment for 1, 7, and 14 days, and 1, 2 and 4 months at 23°C and 50°C. The changes in tensile (breaking strength), modulus, elongation and tear shall be determined after immersion for 1 day, 7 days, 1 month and 4 months. The properties for these various exposure times can be plotted on log-log graph paper and curves can be extrapolated to 40 months to determine the physical property for that time. This data will assist in determining the properties after long-term service. The specific nature of the FML being tested should be considered when interpreting the data.

D. SIGNIFICANCE

1. The limitations of the results obtained from this test should be recognized.
2. Correlation of test results with the actual performance or serviceability of FML materials is necessarily dependent upon the similarity between the testing and end-use conditions. For applications involving continuous immersion, the data obtained in short time tests are of interest only in eliminating the most unsuitable materials or indicating a probable relative order of resistance to chemical reagents.
3. The selection of test conditions should take into account the manner and duration of contact with the chemical environment, the temperature of the system, and other performance factors involved in the particular application. If the highest expected temperature in service exceeds the 50°C recommended in this appendix, then use the higher temperature.
4. Note should be taken that different ratios or even trace amounts of different materials in the immersion liquid may affect the FML in an entirely different manner if concentrated or localized even for short periods of time in repeat tests or in actual application. Trace amounts of deleterious chemicals can be cumulative; this may require a repeated supply of chemical liquid to show the true immersion effect.

E. APPARATUS

1. Balance - a chemical balance accurate to 1 mg.
2. Micrometers - Micrometers capable of measuring dimensions of test specimens to 0.025 mm (0.001 in).
3. Room or enclosed space capable of being maintained at the standard laboratory atmosphere, at temperature $23 \pm 2^\circ\text{C}$ and relative humidity of $50 \pm 5\%$ (ASTM D618).
4. Containers - Suitable containers for immersing specimens in chemical reagents. They must be resistant to the corrosive effects of the reagents being used. Safety precautions must be taken when using highly volatile reagents at elevated temperatures.
5. Oven or Constant-temperature Bath - Capable of maintaining temperature within $\pm 2^\circ\text{C}$ of the specified test temperatures.

6. **Testing Devices** - Testing devices for determining specified strength properties of specimens before and after immersion, conforming to the requirements prescribed in the ASTM methods of test for the specific properties being determined.

F. TEST ENVIRONMENTS

The FML liner material should be immersed in the actual chemical process solutions to be provided by the plant involved. If this is not possible, a synthesized solution may be used and must include all chemicals, especially solvents, even though they are present in small quantities. See Section D.4 concerning special studies with aggressive trace materials.

Caution: In all cases, it is necessary to determine whether the solution is homogenous or consists of more than one phase. When a multiphase solution exists, test samples must be placed in each of the phases. Each phase should be in a separate container. Past experience indicates that a solvent has limited solubility in an aqueous system and may form a separate layer either on top or bottom of the liquid. It is likely that the solvent phase may adversely affect the liner material while the aqueous phase may not. If highly volatile chemicals are part of the solution being tested, the solution should be changed at equal time intervals (weekly or monthly) so as to compensate for any escaping components of the chemical environment.

G. TEST SPECIMENS

The type and dimensions of test specimens to be used for original and immersion testing shall be those described in Section J.3. for each type of FML. Specimen surface area greatly affects the weight change due to immersion in chemical reagents. Thickness influences percentage dimension change as well as percentage change in mechanical properties. Consequently, comparison of materials should be made only on the basis of results obtained from specimens of identical dimensions and like methods of specimen preparation. The number of specimens used shall be as stated in Sections B and C. The specimens shall be as follows: specimens from sheet material shall be cut from a representative sample of material in a manner depending upon the tests to be performed and the thickness of the sheet as follows:

1. **Weight and dimension changes** - Standard specimens shall be in the form of bars 76.2 mm (3 in) in length by 25.4 mm (1 in) in width by the thickness of the material. 2 inch by 1 inch specimens or 2-inch diameter discs can be alternates.)
2. **Mechanical property changes** - Standard machined, sheared, or cut tensile specimens shall be used according to the methods of test prescribed.

H. CONDITIONING

1. Condition the test specimens at $23 \pm 2^{\circ}\text{C}$ ($73.4 \pm 3.6^{\circ}\text{F}$) and 50 ± 5 percent relative humidity for not less than 40 hours prior to test.

2. Test conditions - Conduct tests at the standard temperatures of $23 \pm 2^{\circ}\text{C}$ ($73.4 \pm 3.6^{\circ}\text{F}$) and $50 \pm 2^{\circ}\text{C}$ ($122 \pm 3.6^{\circ}\text{F}$). In cases where the FML material will have a chemical environment at elevated temperatures, the immersion testing shall be run at the elevated temperature if higher than the above.

I. PROCEDURE I - WEIGHT AND DIMENSION CHANGES

1. Weigh each conditioned specimen separately and measure its thickness at the center and its length and width to the nearest 0.25 mm (0.001 in). In the case of laminates, edge swelling is not uncommon under certain conditions. Consequently, it may be necessary to measure thickness both at the center and at the edges and report the percentage change separately for each position.
2. Place specimens in appropriate containers for the chemicals being used and allow the specimens to be totally immersed in fresh chemical for the appropriate time in the standard laboratory atmosphere. Suspend the specimens to avoid any contact with the walls or bottom of the container. For specimens of thin sheeting or those having a lower density than the chemical, it may be necessary to attach small weights such as nichrome wire to prevent floating or curling. Several specimens of a given material may be immersed in the same container provided sufficient reagent is allowed for the total surface area exposed and the specimens do not touch each other. The quantity of chemical solution shall be approximately 40 ml/in² of total specimen surface area.

For test at other than room temperatures, it is recommended that the test temperature be 50°C or at the highest expected service temperature, whichever is the highest. It is important that the test solution be at the elevated test temperature before the specimens are immersed. In the event that the liner is expected to impound certain substances in trace quantities which can be aggressive to FML materials, special investigations should be instituted by the testing agency.

3. Stir the test solutions every 24 hours by moderate manual rotation of the containers or other suitable means. In making tests for longer periods of time than 7 days, the containers should be stirred once each day during the first week, and once each week thereafter. Where the field service condition will involve aeration or other continuous agitation, the containers should be stirred daily.
4. After the test period, individually remove each specimen from the chemical solution, blot excess material, dip into acetone, wipe and dry with lint-free material, immediately weigh in a weighing bottle, remeasure its dimensions and place back into chemical environment until next time period. When dealing with an oily material, it may be necessary to follow the following procedure: wipe and dry with lint-free material; dip into detergent solution; wipe and dry with lint-free material; dip into water and then acetone; wipe and dry with lint-free material; dip into water and then acetone; wipe and dry with lint-free material; and weigh and measure immediately. Some specimens may become tacky due to dissolved material on the surface or

solvent absorbed throughout the specimen. Take care in wiping such specimens not to disturb or contaminate the surface.

5. Observe the appearance of each specimen after exposure to chemical reagent. Observe and report appearance on the basis of examination for evidence of blistering, loss of gloss, developed texture, decomposition, discoloration, swelling, tackiness, crazing, bubbling, cracking, softening, solubility, etc. For some materials, absorption of the reagent over the immersion period is nearly balanced by the removal of soluble constituents. This type of behavior may be revealed by comparing the initial conditioned weight of the specimen with its weight when dried for 7 days at 23°C and 50 percent relative humidity, after removal from the chemical reagent. (A final weight lower than the initial weight may indicate removal of soluble constituents. However, only for particular combinations of reagent and test specimen can this weight difference be considered as due strictly to the removal of soluble constituents.) If this drying out procedure is used, it should be tried after all test-time periods have elapsed.

J. PROCEDURE II - MECHANICAL PROPERTY CHANGES

1. Immerse and handle the mechanical test specimens in accordance with the instructions given under Procedure I (Sections 2, 3 and 4).
2. Determine the mechanical properties of identical nonimmersed and immersed specimens in accordance with the standard methods for the physical property test described. Make mechanical property tests as nonimmersed and immersed specimens prepared from the same sample or lot of material in the same manner and run under identical conditions. Test immersed specimens immediately after they are removed from the test solution. Where specimens are exposed to test solutions at elevated temperatures, they shall be placed in another container of the reagent at the standard laboratory temperature for approximately one hour to effect cooling prior to testing.
3. Test samples for materials with fiber scrim support - The effect of chemicals on the liner material without support material must be determined because it is the main chemical barrier while the function of the scrim is to provide added mechanical properties. Most of the time, the liner material without support will have to be a laboratory-milled sample of the same formulation, milled to a thickness of 20 or 30 mils. The processing conditions of laboratory-prepared samples should be as close as possible to actual factory conditions.

All samples containing a fiber scrim support must be flood-coated along all exposed edges with a solution recommended by the FML manufacturer. This solution will typically contain 5 - 15% solids dissolved in a solvent (or mixture of solvents). The solids content is usually the FML formula or simply the base polymer used.

The physical properties after immersion are determined using the original unimmersed thickness or cross-sectional area, as described in ASTM D471.

4. Test samples for material with no scrim - These test samples are designed to measure the mechanical and physical properties of the liner material. Tests shall be conducted as prescribed and the properties after immersion are determined using the original unimmersed thickness or cross-sectional area, as described in ASTM D471.
5. Condition of samples before physical testing - After the samples have been removed from the test solution, they should be kept saturated with the test solution until just before testing. If the test solution contains organic solvents, the coupons should be wrapped in aluminum foil during this interval to prevent loss of solvent. In many cases, a material that has been degraded by solvent will regain almost all its original properties after the solvent has evaporated away. The time between removal from solution and testing should be kept as short as practical.
6. Test data required:

Crosslinked elastomers unsupported - ASTM D412 (Method A)

- Breaking strength, pounds/inch width
- Elongation at ultimate, percent
- Modulus at 100 percent elongation

Thermoplastics, unsupported

Materials without a yield point - ASTM D882

- Breaking strength, pounds/inch width
- Elongation at break, percent
- Modulus at 100 percent elongation, pounds/inch width

Materials with a yield point - ASTM D683

- Breaking strength at yield and break, pounds/inch width
- Elongation at yield and break, percent
- Modulus of elasticity, pounds/inch width

Supported flexible membrane liners

Supported finished FML material - ASTM D751

- Breaking strength, Grab Method, pounds or Strip Method, pounds/inch width

Ply adhesion, all supported FML - ASTM D413, Machine method, strip specimen, Type A, 180° peel, pounds/inch width

Tear, unsupported FML - ASTM D1004

Visual inspection, unsupported and supported FML - Procedure I (Sections 1 through 5)

K. Procedure III - Effect of Strain on Mechanical Properties

1. Standard specimens shall be in the form of bars 75.2 mm (3 inches) in length and 25.4 mm (1 inch) in width by thickness of the material.
2. Form a bent loop from the standard specimen by folding the specimen together and holding the ends together with a suitable fastener or adhesive which is resistant to the test solution. Approximately 2 inches of the specimen shall be in contact with itself.
3. The specimens should be conditioned and immersed as in Procedure I (Section I).
4. After immersion periods of 7 days for initial evaluation and 4 months for long-term evaluation, the specimen shall be inspected for visible deterioration as described in Procedure I.
5. This test is qualitative in character and to be used to identify materials which are highly susceptible to deterioration in the chemical solution when strained.

L. Procedure IV - Factory Seams

All seaming methods and techniques should be evaluated in the chemical environment in which they are to be employed. Samples are to be prepared and tested using methods as prescribed in ASTM D3083 (as modified in Appendix A) for unsupported FML and ASTM D751 (Appendix A) for supported FML. These methods provide for the testing of seams in the shear direction. It should be noted that testing in the peel direction (as in ASTM D413) can be a more sensitive test for determining chemical resistance of seams. Samples should be immersed for 7 days for the short-term initial evaluation and 4 months for the long-term test. Samples containing a fabric scrim support must be flood-coated as described earlier (Section J.3.)

M. Report

The report shall include the following:

1. Procedure I:
 - a. Complete identification of the material tested including type source, manufacturer's code, form and previous history.
 - b. Temperature of tests.
 - c. Test solutions
 - d. Duration of immersion

- e. Initial length, width and thickness of each specimen, in inches, measured to the nearest 0.025 mm (0.001 in)
 - f. Initial weight of each specimen in grams to ± 0.005 g
 - g. Length, width and thickness after immersion
 - h. Weight after immersion
 - i. Average percentage increase or decrease in length and width, and in the thickness, taking the dimensions of the conditioned specimen as 100 percent.
 - j. Average percentage gain or loss in weight calculated to the nearest 0.01 percent, taking the conditioned weight as 100 percent.
 - k. General appearance of specimens after immersion.
2. Procedure II:
- Items 1 through 4 as for Procedure I and the following:
- a. Specimen type and dimensions
 - b. Method of test
 - c. Mechanical properties of identical nonimmersed and immersed specimens
 - d. Average percentage increase or decrease in mechanical properties, taking the properties of the conditioned nonimmersed specimens as 100 percent.
3. Procedure III
- General appearance of specimens after exposure
4. Procedure IV
- a. Original bonded seam strength
 - b. Bonded seam strength after immersion
 - c. Average change in bonded seam strength using original bonded seam strength as 100 percent
 - d. The calculated percent change of all measured properties at 40 months based upon a log-log plot of test data and time for the results for tests at time increments prescribed.

APPENDIX C

PLOTS OF WEIGHT CHANGE VERSUS TIME

INDEX

<u>Figure No.</u>	<u>Liner Material</u>	<u>Test Conditions</u>
C-1	PVC; PVC-OR; CPE	Air; 23°C
C-2	Hypalon; HDPE; XR-5; EPDM; Neoprene	Air; 23°C
C-3	PVC; PVC-OR; CPE	Distilled water; 23°C
C-4	Hypalon; HDPE; XR-5 EPDM; Neoprene	Distilled water; 23°C
C-5	PVC; PVC-OR; CPE	100 mg/l TCE; 23°C
C-6	Hypalon; HDPE; XR-5; EPDM; Neoprene	100 mg/l TCE; 23°C
C-7	PVC; PVC-OR; CPE	Water saturated with TCE; 23°C
C-8	Hypalon; HDPE; XR-5; EPDM; Neoprene	Water saturated with TCE; 23°C
C-9	PVC; PVC-OR; CPE	TCE saturated with water; 23°C
C-10	HDPE; XR-5; EPDM; Neoprene	TCE saturated with water; 23°C
C-11	PVC; PVC-OR; CPE	Air; 50°C
C-12	Hypalon; HDPE; XR-5; EPDM; Neoprene	Air; 50°C
C-13	PVC; PVC-OR; CPE	Distilled water; 50°C
C-14	Hypalon; HDPE; XR-5; EPDM; Neoprene	Distilled water; 50°C
C-15	PVC; PVC-OR; CPE	100 mg/l TCE; 50°C
C-16	Hypalon; HDPE; XR-5; EPDM; Neoprene	100 mg/l TCE; 50°C

APPENDIX C

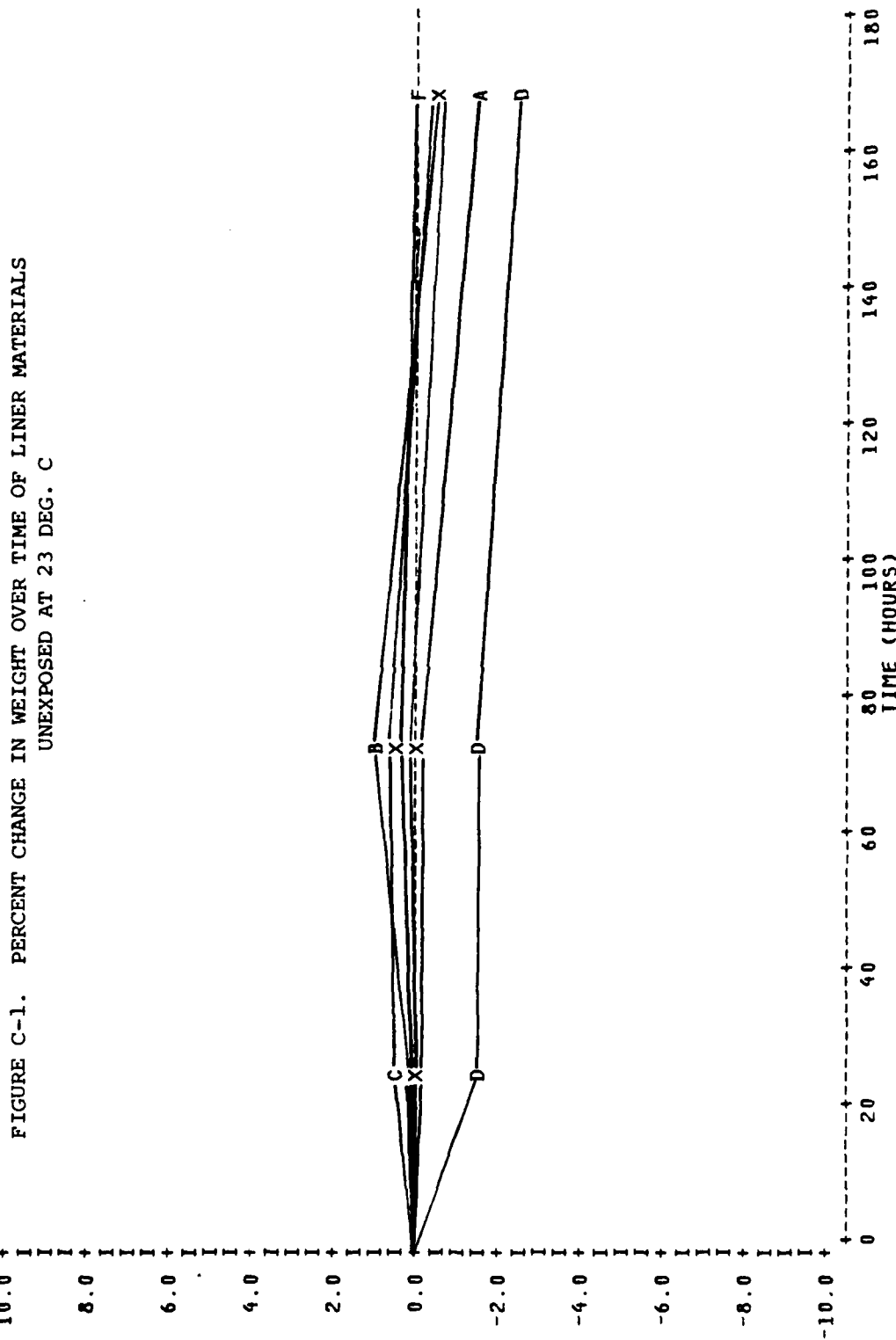
PLOTS OF WEIGHT CHANGE VERSUS TIME

INDEX (Continued)

<u>Figure No.</u>	<u>Liner Material</u>	<u>Test Conditions</u>
C-17	PVC; PVC-OR; CPE	Water saturated with TCE; 50°C
C-18	Hypalon; HDPE; XR-5; EPDM; Neoprene	Water saturated with TCE; 50°C
C-19	PVC; PVC-OR; CPE	Water saturated with TNT; 50°C
C-20	Hypalon; HDPE; XR-5; EPDM; Neoprene	Water saturated with TNT; 50°C
C-21	PVC; PVC-OR; CPE	Water saturated with RDX; 50°C
C-22	Hypalon; HDPE; XR-5; EPDM; Neoprene	Water saturated with RDX; 50°C

MEASURED
WEIGHT CHANGE (%)

FIGURE C-1. PERCENT CHANGE IN WEIGHT OVER TIME OF LINER MATERIALS
UNEXPOSED AT 23 DEG. C

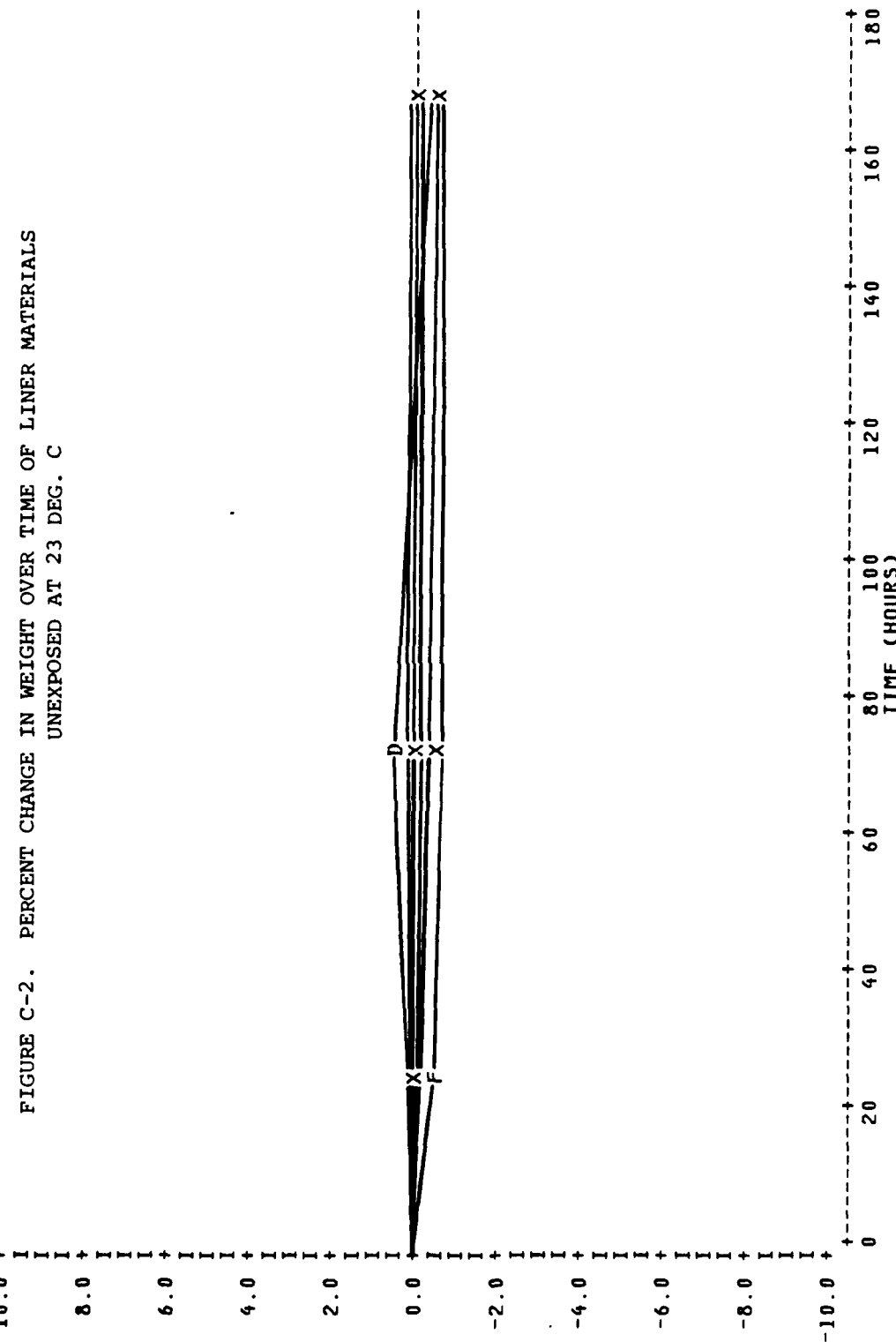


LEGEND:

SYMBOL	MATERIAL(S)	MAKER	CHEMICAL	TEMP	JAR
A	PVC	PANTASOTE	UNEXPOSED	23	1
B	PVC	PALCO	UNEXPOSED	23	4
C	PVC-OR	PANTASOTE	UNEXPOSED	23	7
D	PVC-OR	PALCO	UNEXPOSED	23	10
E	CPE	PALCO	UNEXPOSED	23	13
F	CPE	PANTASOTE	UNEXPOSED	23	128
X	Overlapping data points				

MEASURED
WEIGHT CHANGE (%)

FIGURE C-2. PERCENT CHANGE IN WEIGHT OVER TIME OF LINER MATERIALS
UNEXPOSED AT 23 DEG. C



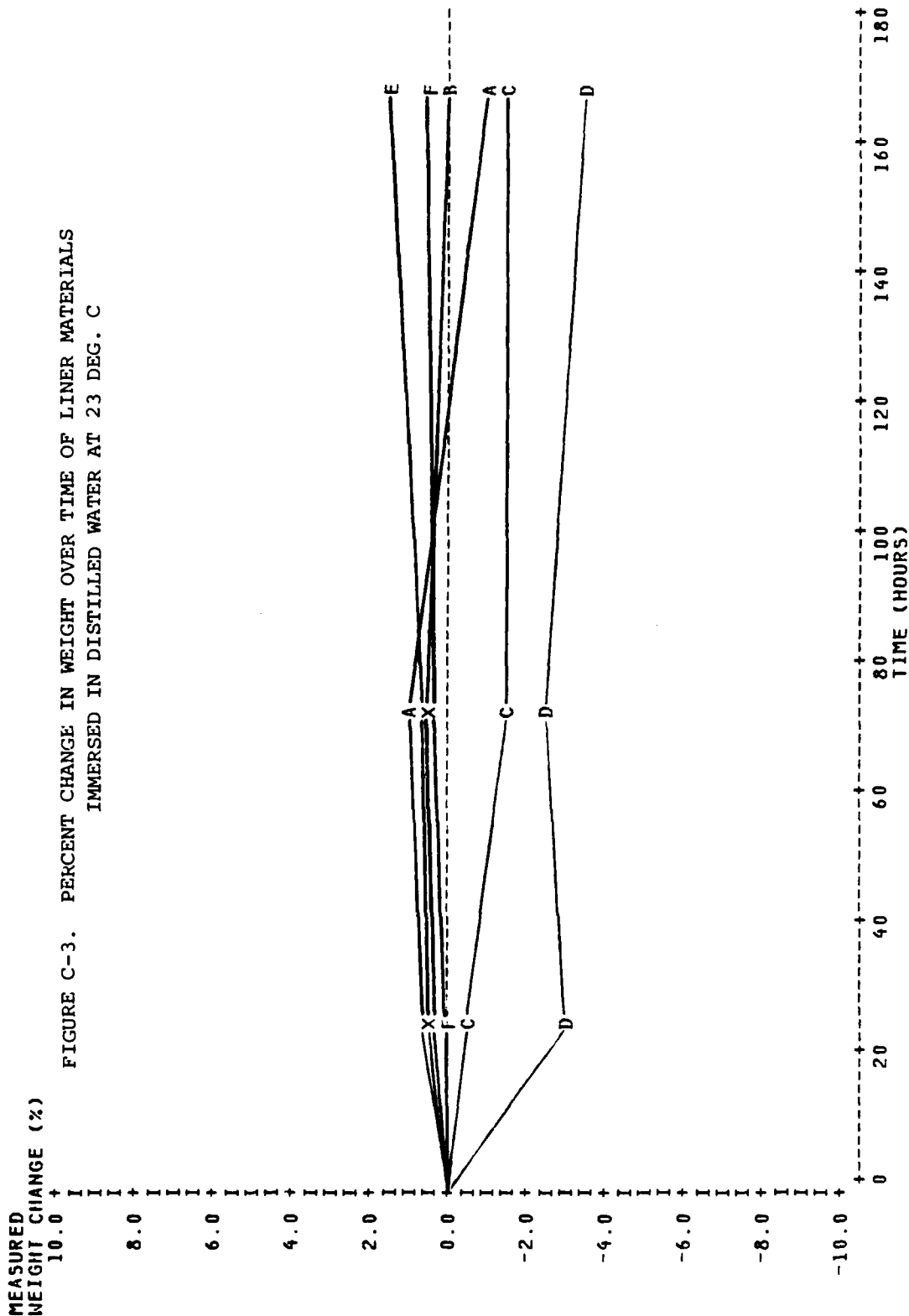
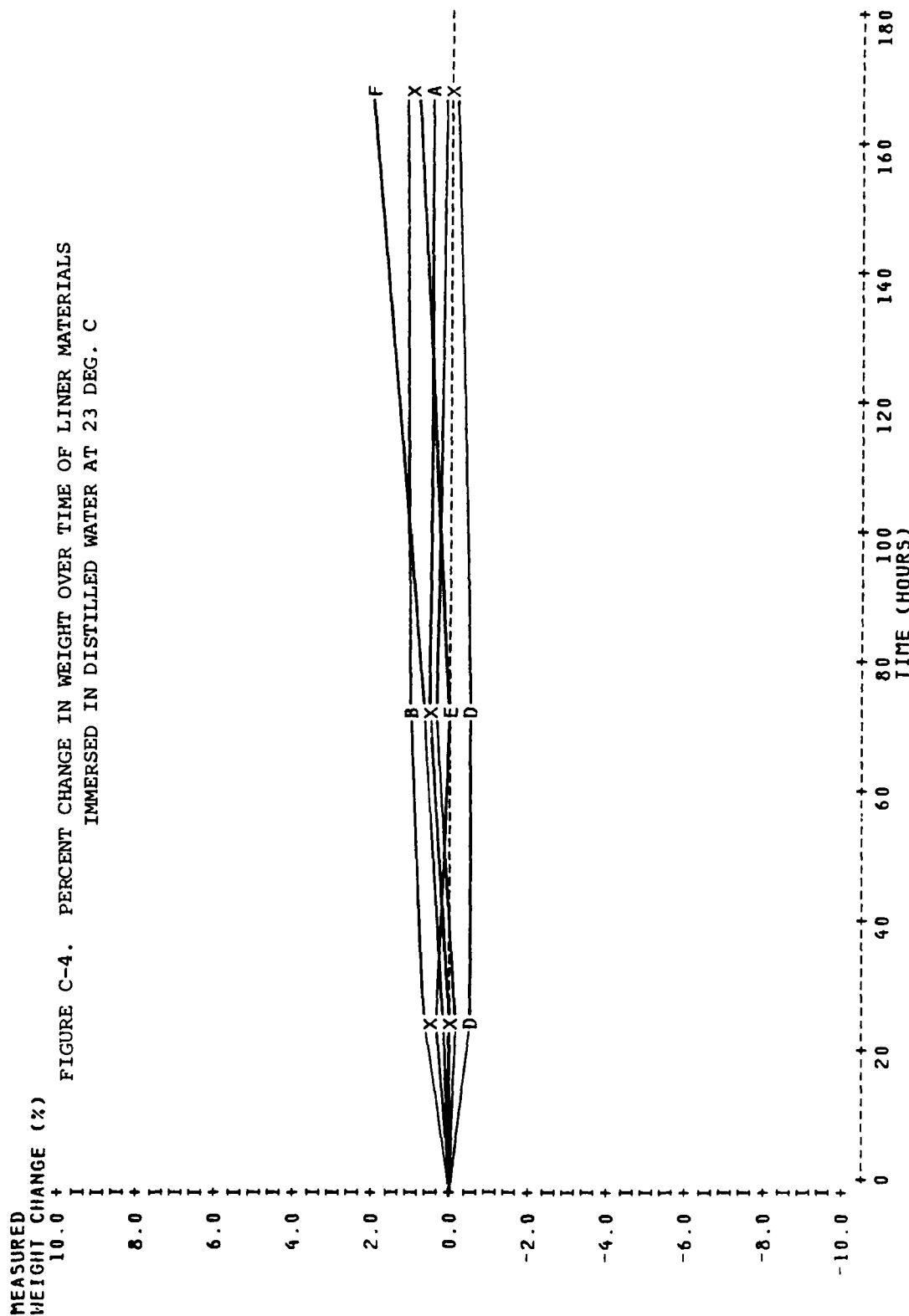


FIGURE C-4. PERCENT CHANGE IN WEIGHT OVER TIME OF LINER MATERIALS IMMERSIED IN DISTILLED WATER AT 23 DEG. C

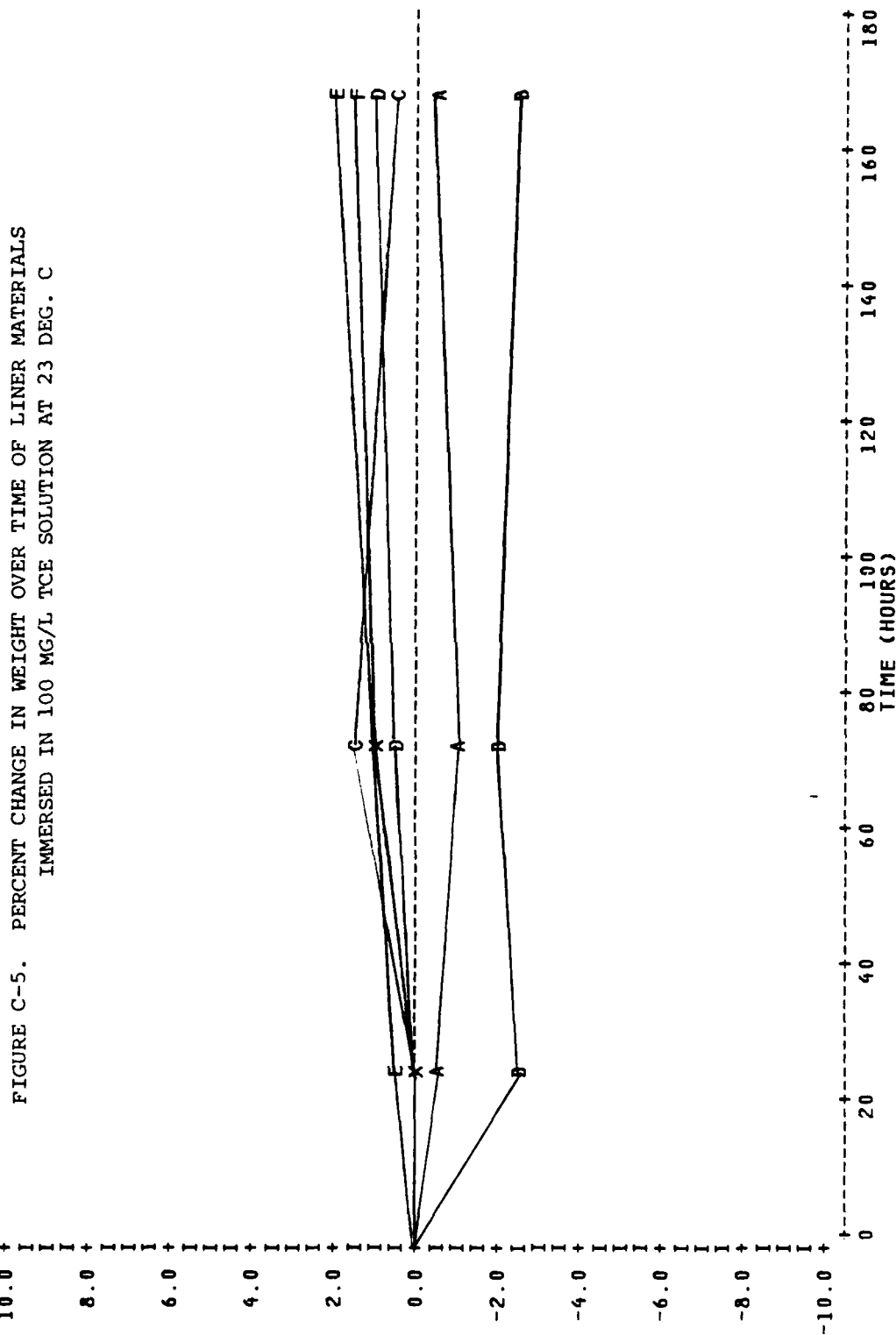


LEGEND:					
SYMBOL	MATERIAL(S)	MAKER	CHEMICAL	TEMP	JAR
A	HYPALON	STEVENS	DISTILLED WATER	23	17
B	HYPALON	PANTASOTE	DISTILLED WATER	23	20
C	HDPE	SCHLEGEL	DISTILLED WATER	23	23
D	XR-5	SHELTER-RITE	DISTILLED WATER	23	26
E	EPDM	CARLISLE	DISTILLED WATER	23	29
F	NEOPRENE	CARLISLE	DISTILLED WATER	23	32

Overlapping data points

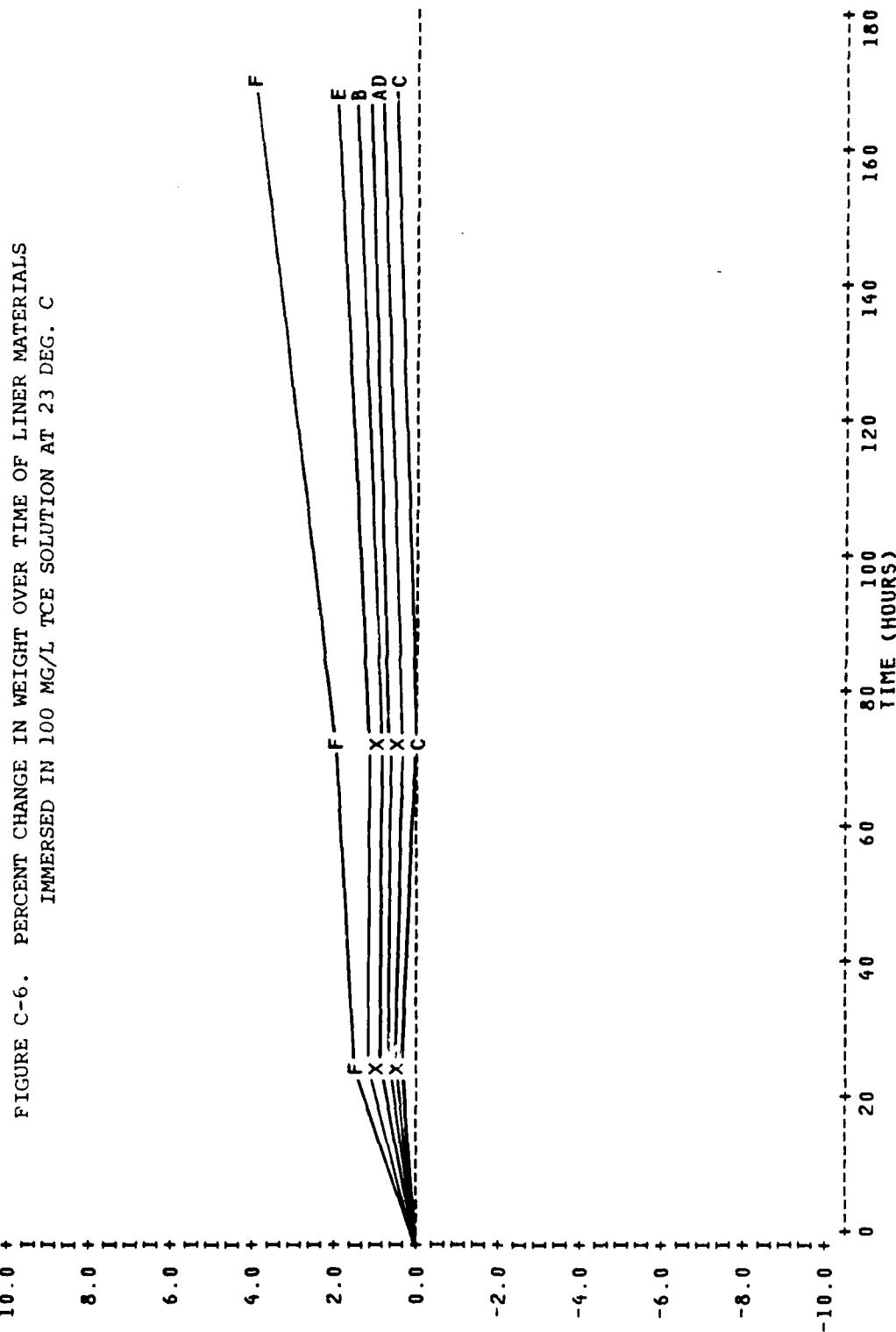
MEASURED
WEIGHT CHANGE (%)

FIGURE C-5. PERCENT CHANGE IN WEIGHT OVER TIME OF LINER MATERIALS
IMMERSED IN 100 MG/L TCE SOLUTION AT 23 DEG. C

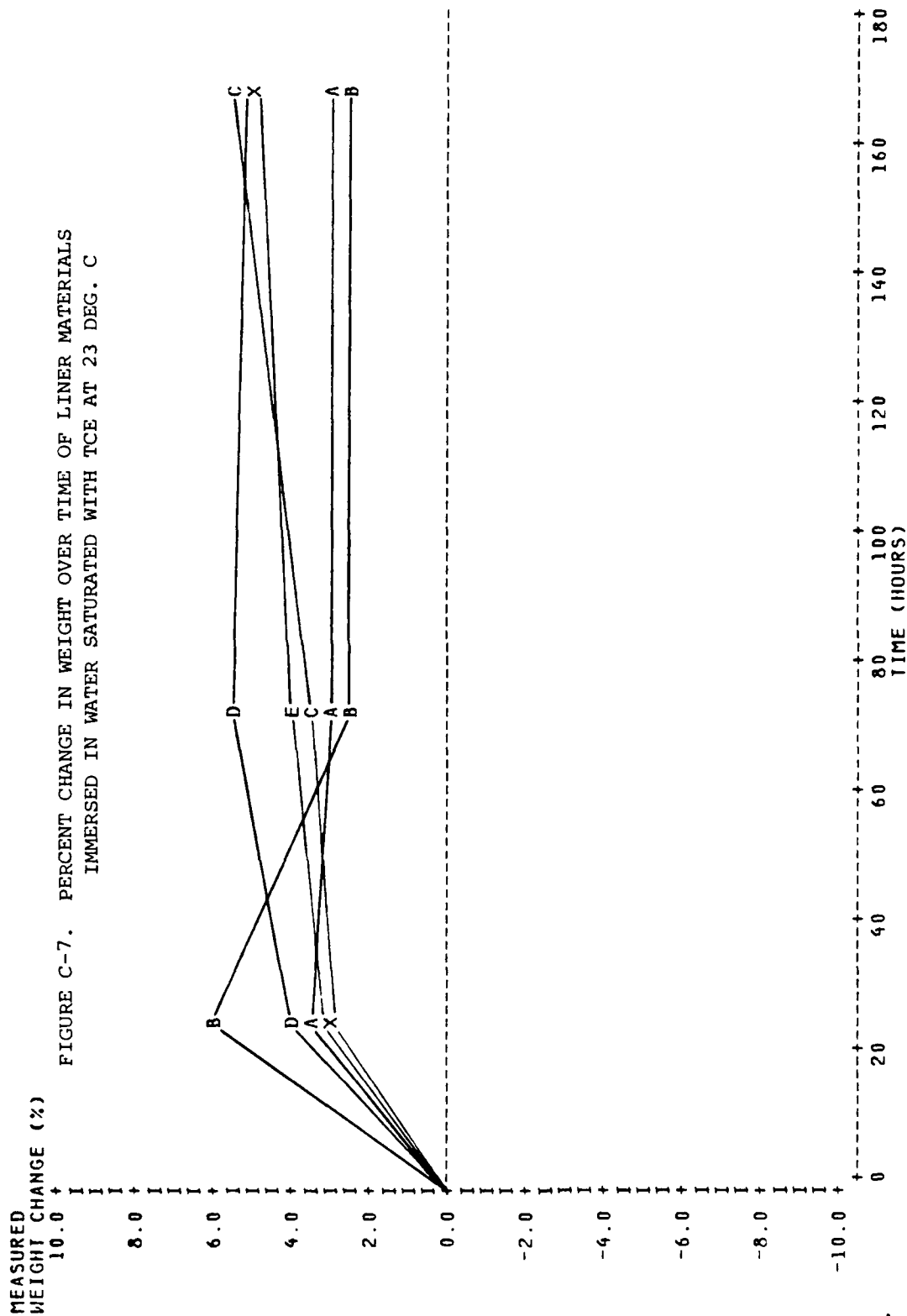


MEASURED
WEIGHT CHANGE (%)

FIGURE C-6. PERCENT CHANGE IN WEIGHT OVER TIME OF LINER MATERIALS
IMMERSED IN 100 MG/L TCE SOLUTION AT 23 DEG. C



LEGEND:		SYMBOL		MATERIAL(S)	MAKER	CHEMICAL	TEMP	JAR
A		HYPALON		STEVEN'S		TCE 100 MG/L	23	109
B		HYPALON		PANTASOTE		TCE 100 MG/L	23	110
C		HDPE		SCHLEGEL		TCE 100 MG/L	23	111
D		XR-5		SHELTER-RITE		TCE 100 MG/L	23	112
E		EPDM		CARLISLE		TCE 100 MG/L	23	113
F		NEOPRENE		CARLISLE		TCE 100 MG/L	23	114
X		Overlapping data points						



LEGEND:	SYMBOL	MATERIAL (S)	MAKER	CHEMICAL	TEMP	JAR
	A	PVC	PANTASOTE	TCE-SAT'D WATER	23	3
	B	PVC	PALCO	TCE-SAT'D WATER	23	6
	C	PVC-OR	PANTASOTE	TCE-SAT'D WATER	23	9
	D	PVC-OR	PALCO	TCE-SAT'D WATER	23	12
	E	CPE	PALCO	TCE-SAT'D WATER	23	15
	X	Overlapping data points				

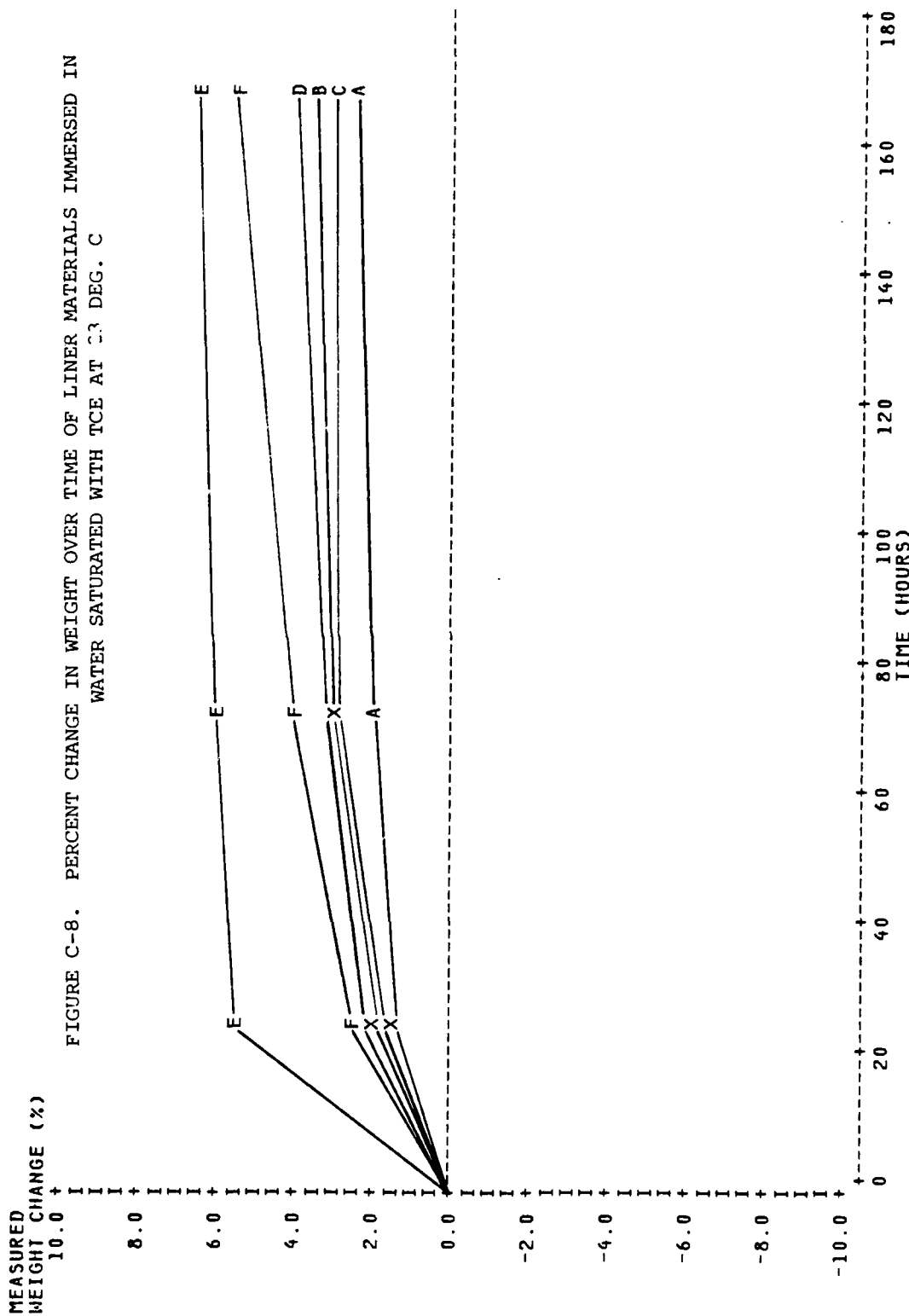


FIGURE C-8. PERCENT CHANGE IN WEIGHT OVER TIME OF LINER MATERIALS IMMERSSED IN WATER SATURATED WITH TCE AT 23 DEG. C

LEGEND:	SYMBOL	MATERIAL(S)	MAKER	CHEMICAL	TEMP	JAR
	A	HYPALON	STEVENS	TCE-SAT'D WATER	23	18
	B	HYPALON	PANTASOTE	TCE-SAT'D WATER	23	21
	C	HDPE	SCHLEGEL	TCE-SAT'D WATER	23	24
	D	XR-5	SHELTER-RITE	TCE-SAT'D WATER	23	27
	E	EPDM	CARLISLE	TCE-SAT'D WATER	23	30
	F	NEOPRENE	CARLISLE	TCE-SAT'D WATER	23	33
	X	Overlapping data points				

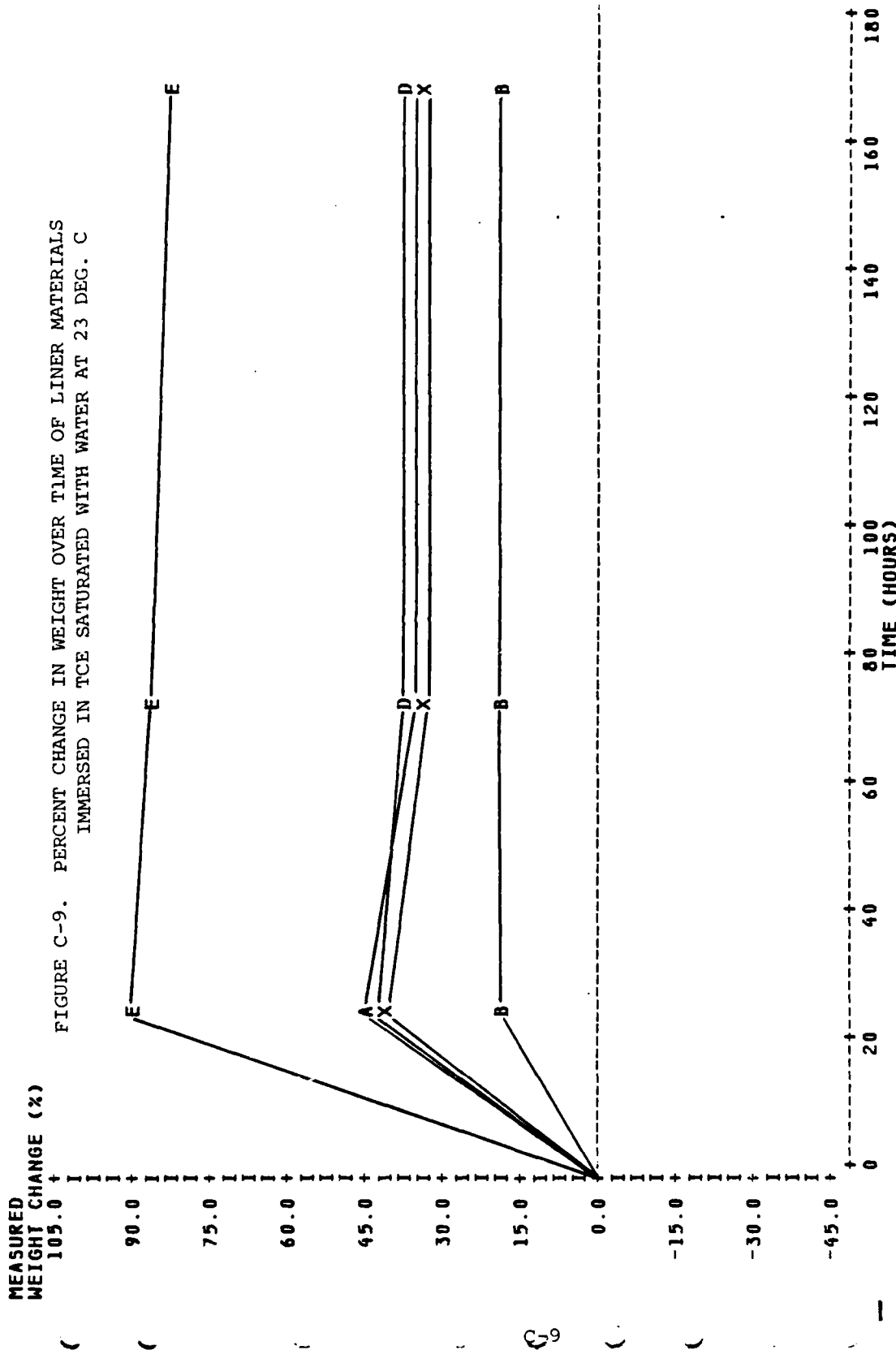
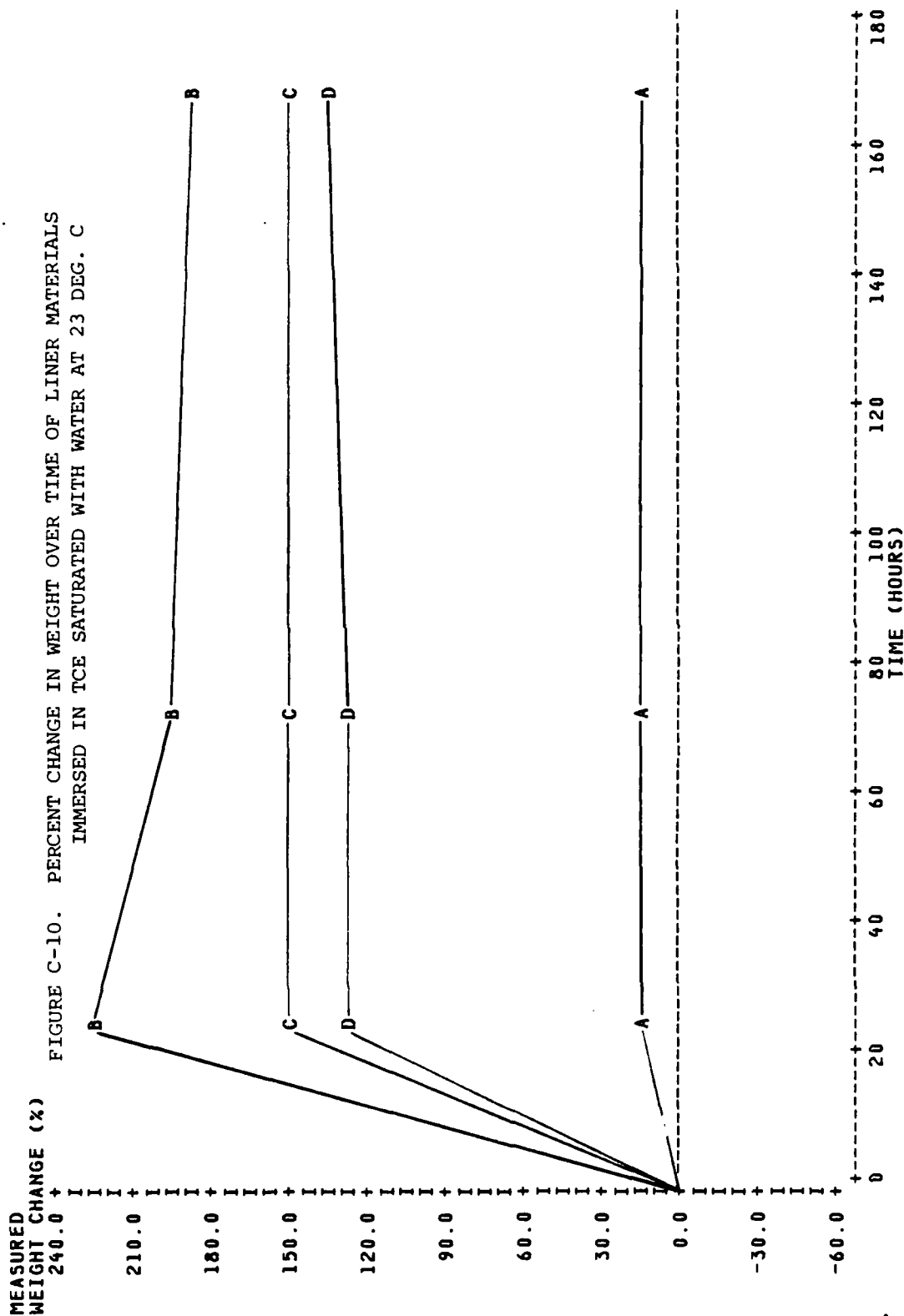


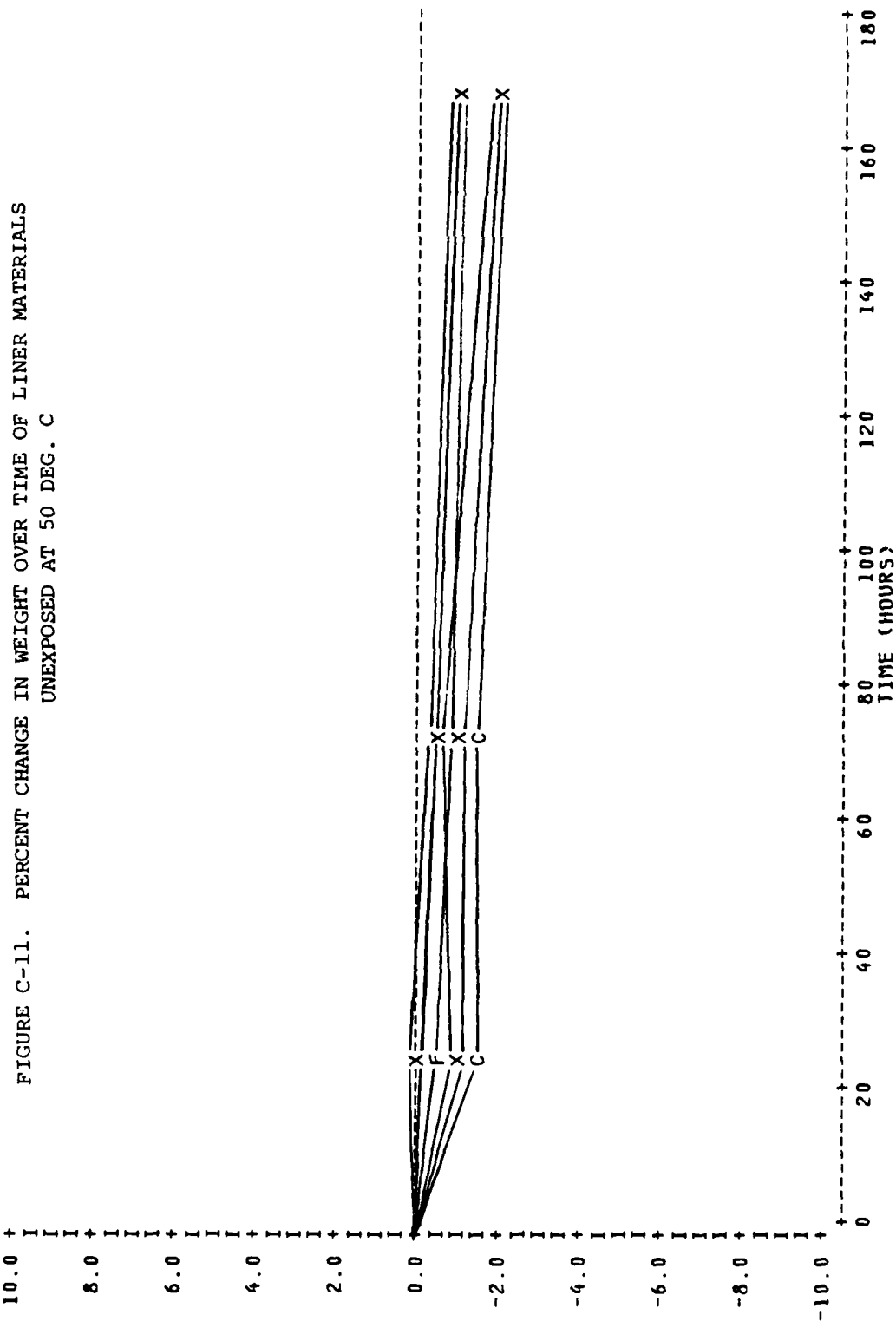
FIGURE C-9. PERCENT CHANGE IN WEIGHT OVER TIME OF LINER MATERIALS IMMERSED IN TCE SATURATED WITH WATER AT 23 DEG. C

LEGEND:	SYMBOL	MATERIAL(S)	MAKER	CHEMICAL	TEMP	JAR
	A	PVC	PALCO	WATER-SAT'D TCE	23	34
	B	PVC	PANTASOTE	WATER-SAT'D TCE	23	35
	C	PVC-OR	PALCO	WATER-SAT'D TCE	23	36
	D	PVC-OR	PANTASOTE	WATER-SAT'D TCE	23	37
	E	CPE	PALCO	WATER-SAT'D TCE	23	38
	X	Overlapping data points				



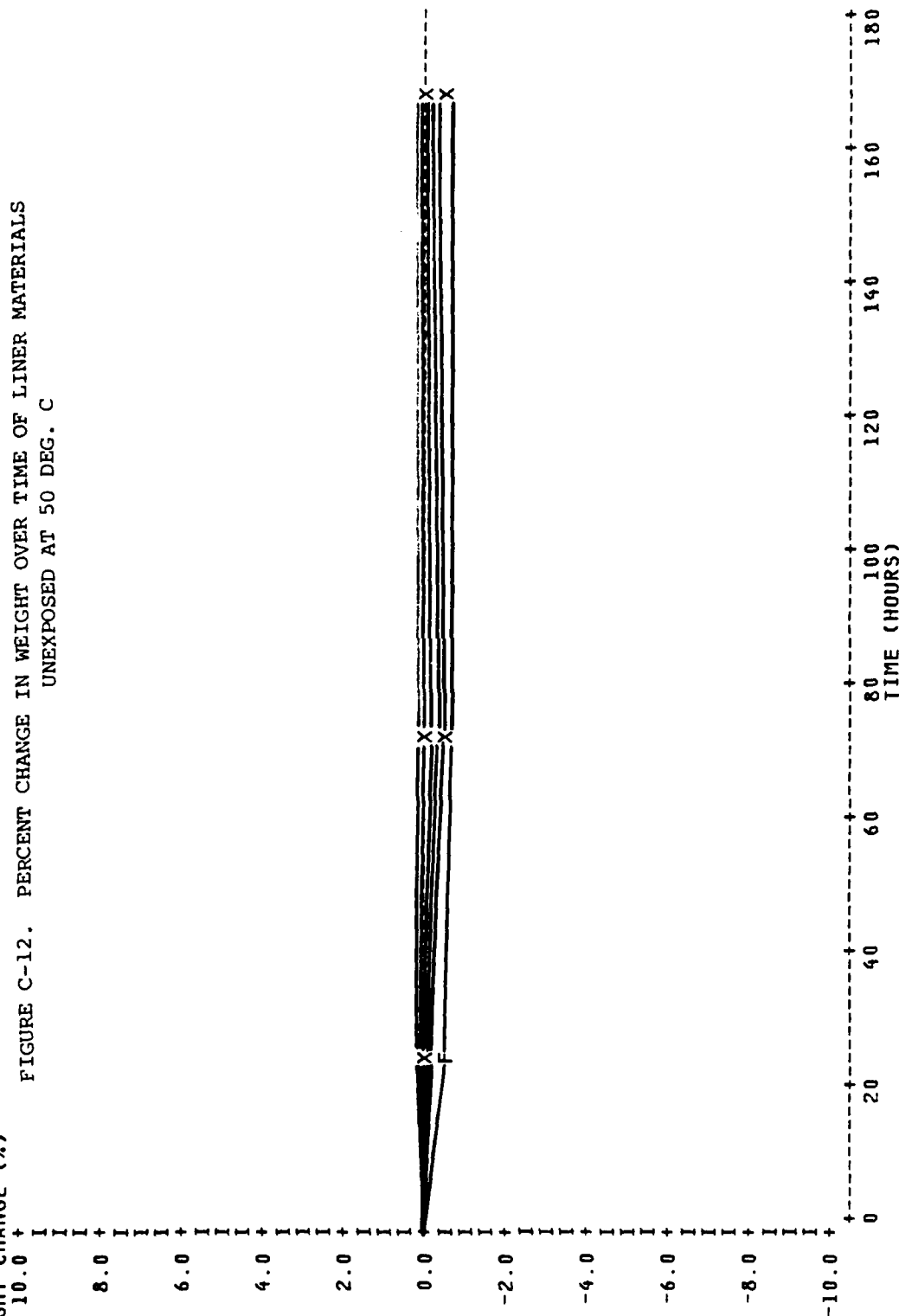
MEASURED
WEIGHT CHANGE (%)

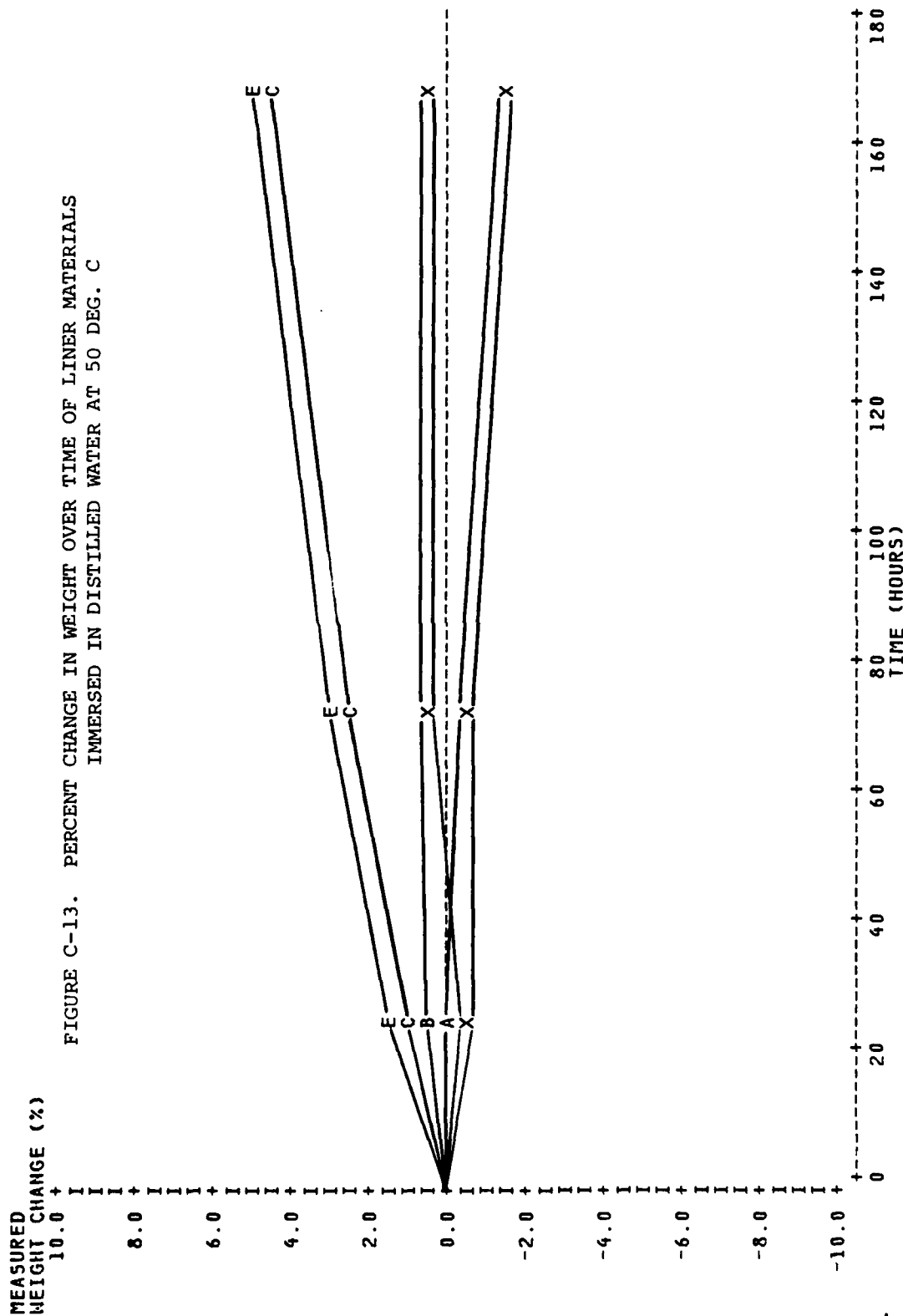
FIGURE C-11. PERCENT CHANGE IN WEIGHT OVER TIME OF LINER MATERIALS
UNEXPOSED AT 50 DEG. C



MEASURED
WEIGHT CHANGE (%)

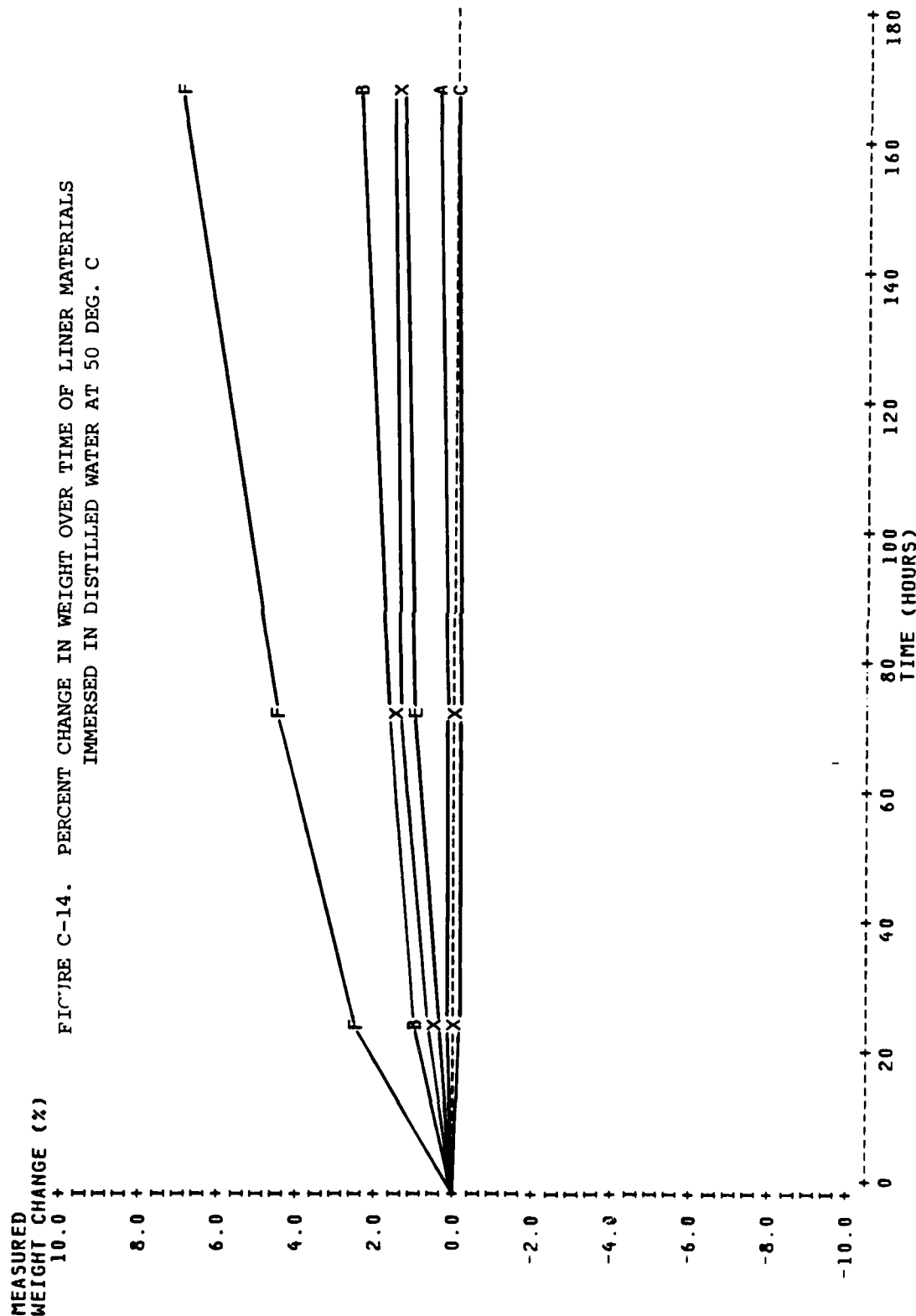
FIGURE C-12. PERCENT CHANGE IN WEIGHT OVER TIME OF LINER MATERIALS
UNEXPOSED AT 50 DEG. C





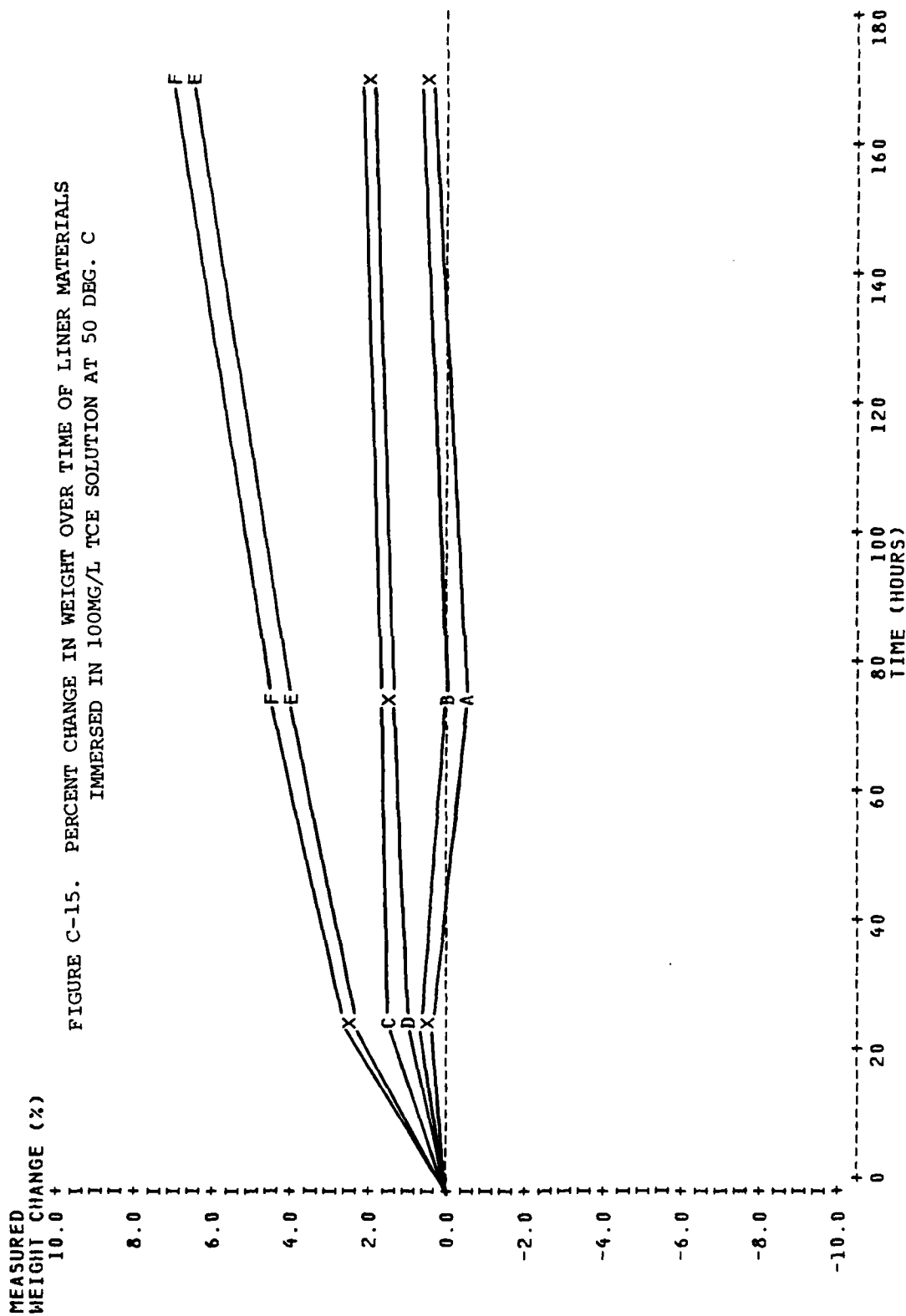
LEGEND:

SYMBOL	MATERIAL(S)	MAKER	CHEMICAL	TEMP	JAR
A	PVC	PALCO	DISTILLED WATER	50	47
B	PVC-OR	PALCO	DISTILLED WATER	50	55
C	CPE	PANTASOTE	DISTILLED WATER	50	67
D	PVC-OR	PANTASOTE	DISTILLED WATER	50	94
E	CPE	PALCO	DISTILLED WATER	50	97
F	PVC	PANTASOTE	DISTILLED WATER	50	100
X	Overlapping data points				



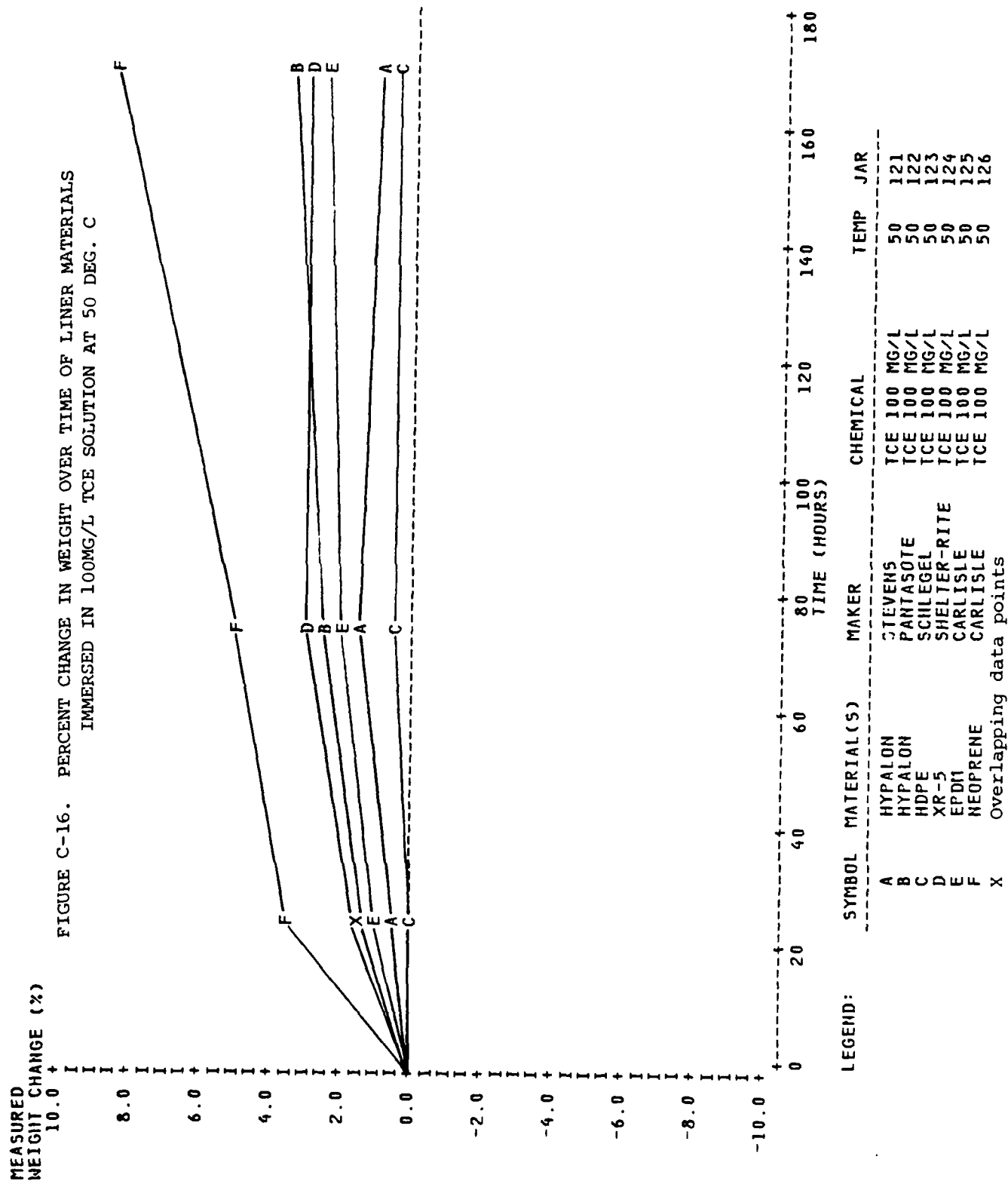
LEGEND:

SYMBOL	MATERIAL(S)	MAKER	CHEMICAL	TEMP	JAR
A	HYPALON	STEVENS	DISTILLED WATER	50	71
B	HYPALON	PANTASOTE	DISTILLED WATER	50	75
C	HDPE	SCHLEGEL	DISTILLED WATER	50	79
D	XR-5	SHELTER-RITE	DISTILLED WATER	50	83
E	EPDM	CARLISLE	DISTILLED WATER	50	87
F	NEOPRENE	CARLISLE	DISTILLED WATER	50	91
X	Overlapping data points				



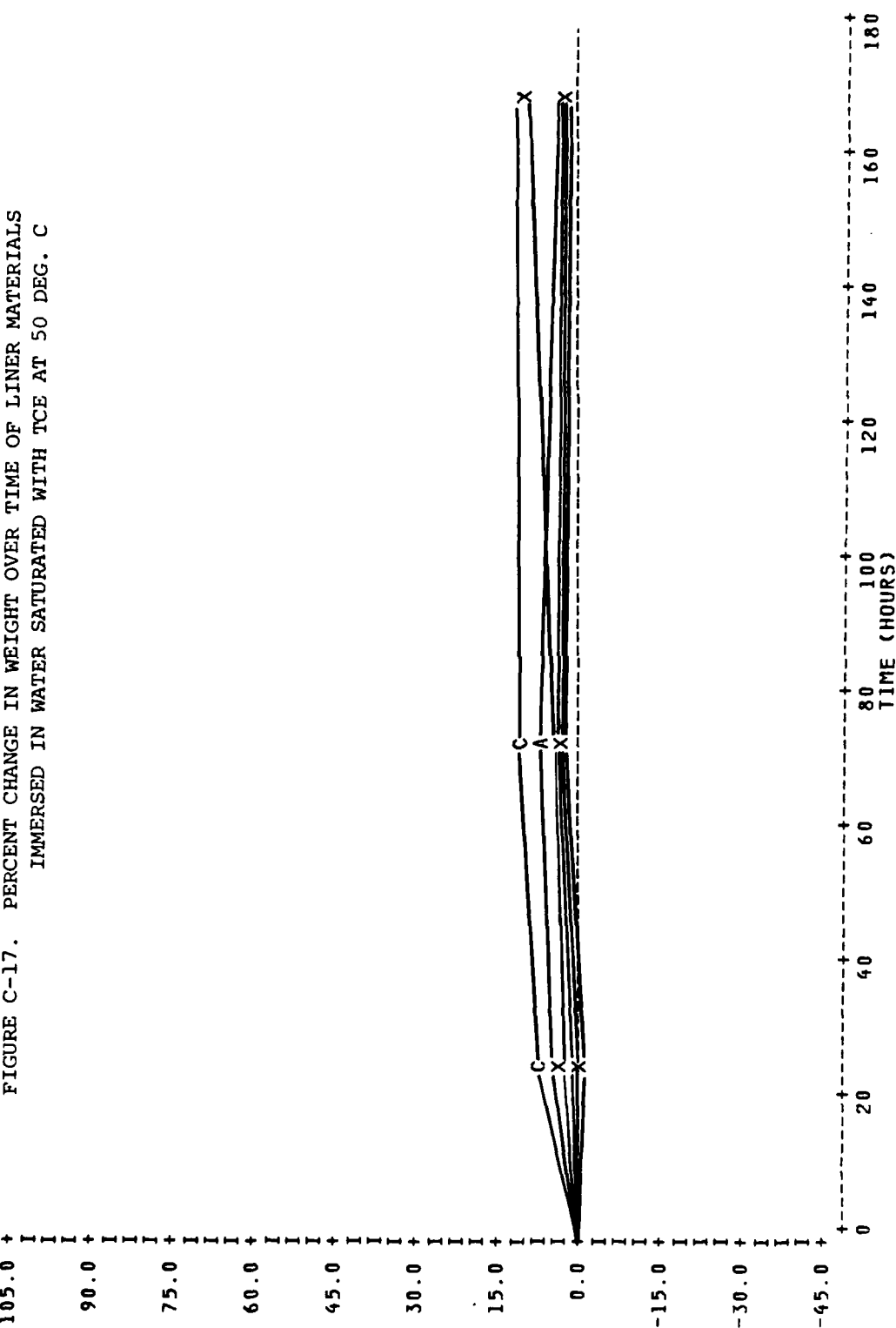
LEGEND:

SYMBOL	MATERIAL(S)	MAKER	CHEMICAL	TEMP	JAR
A	PVC	PALCO	TCE 100 MG/L	50	115
B	PVC	PANTASOTE	TCE 100 MG/L	50	116
C	PVC-OR	PALCO	TCE 100 MG/L	50	117
D	PVC-OR	PANTASOTE	TCE 100 MG/L	50	118
E	CPE	PALCO	TCE 100 MG/L	50	119
F	CPE	PANTASOTE	TCE 100 MG/L	50	120
X	Overlapping data points				



MEASURED
WEIGHT CHANGE (%)

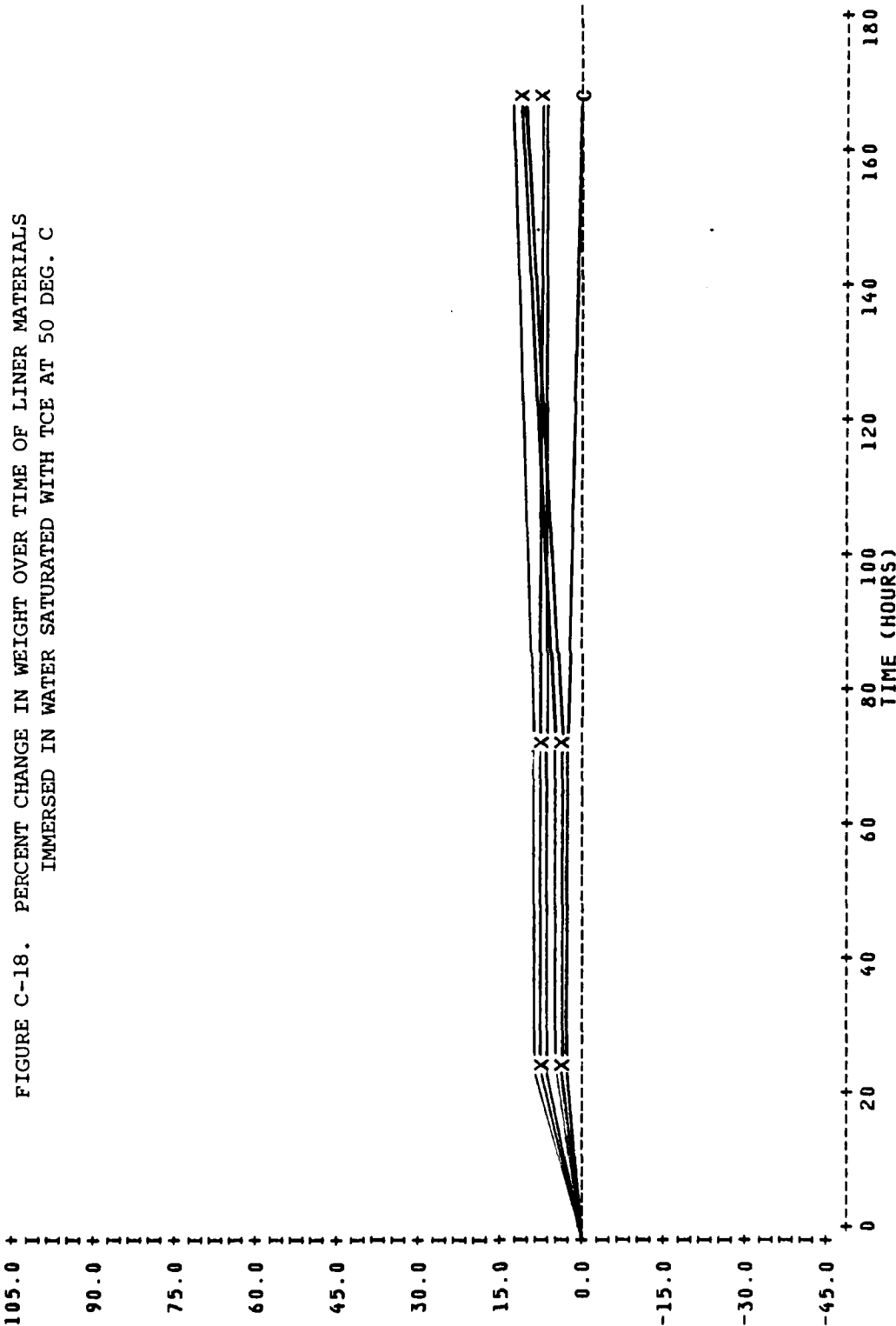
FIGURE C-17. PERCENT CHANGE IN WEIGHT OVER TIME OF LINER MATERIALS
IMMERSED IN WATER SATURATED WITH TCE AT 50 DEG. C



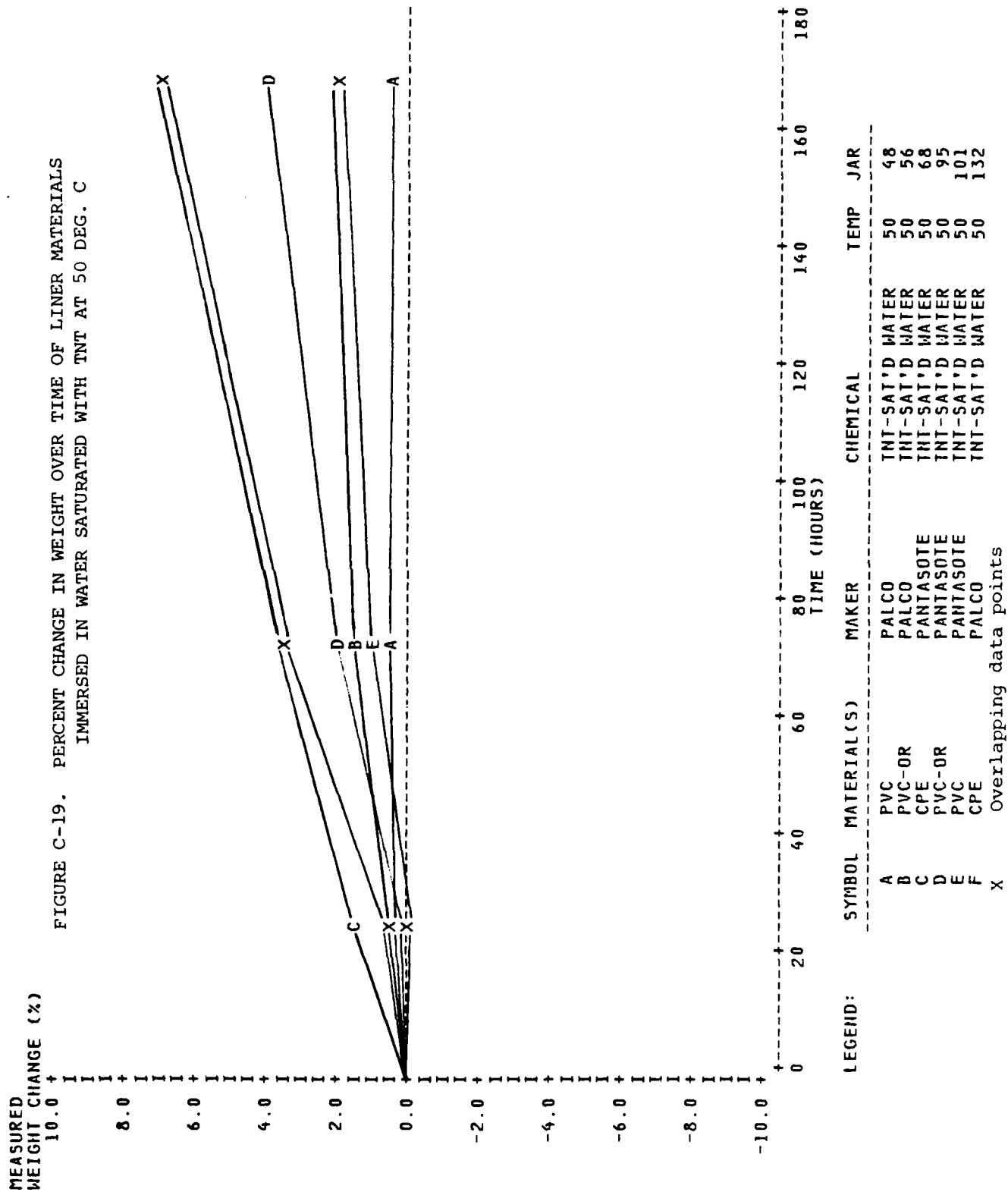
LEGEND:	SYMBOL	MATERIAL(S)	MAKER	CHEMICAL	TEMP	JAR
	A	PVC	PALCO	TCE-SAT'D WATER	50	49
	B	PVC-OR	PALCO	TCE-SAT'D WATER	50	57
	C	CPE	PANTASOTE	TCE-SAT'D WATER	50	69
	D	PVC-OR	PANTASOTE	TCE-SAT'D WATER	50	96
	E	CPE	PALCO	TCE-SAT'D WATER	50	99
	F	PVC	PANTASOTE	TCE-SAT'D WATER	50	102
	X	Overlapping data points				

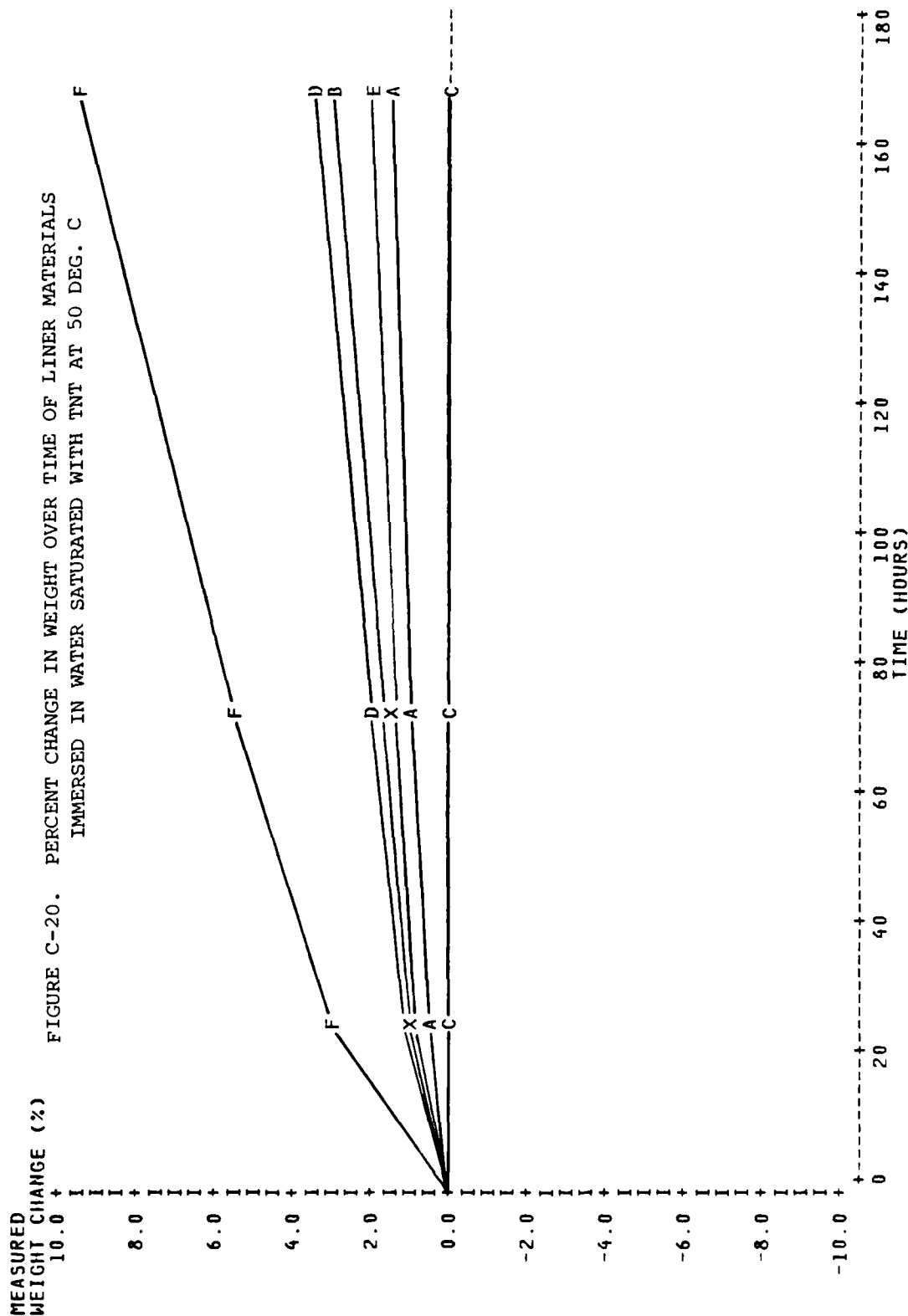
MEASURED
WEIGHT CHANGE (%)

FIGURE C-18. PERCENT CHANGE IN WEIGHT OVER TIME OF LINER MATERIALS
IMMERSED IN WATER SATURATED WITH TCE AT 50 DEG. C



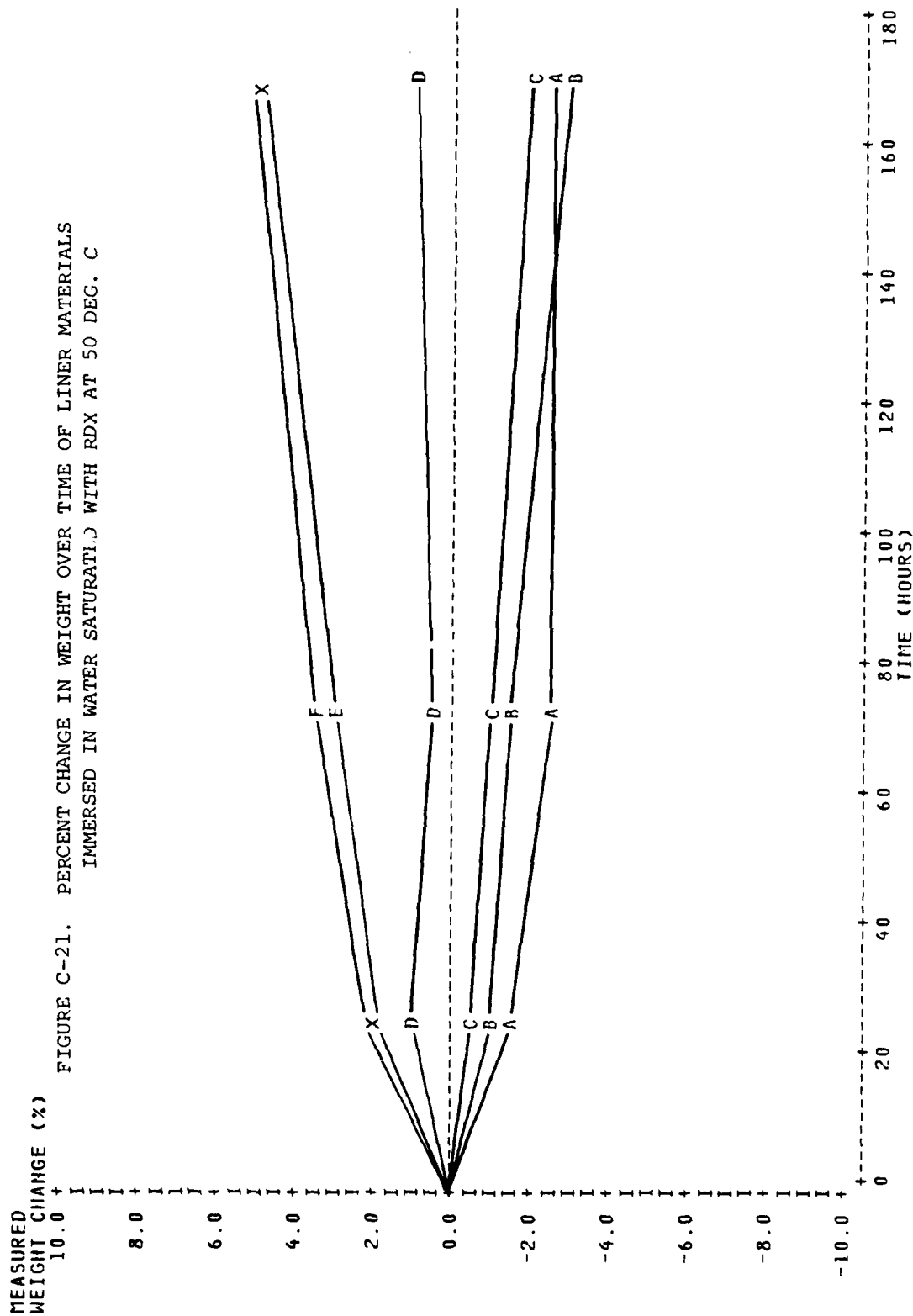
LEGEND:	SYMBOL	MATERIAL (S)	MAKER	CHEMICAL	TEMP	JAR
A		HYPALON	STEVENS	TCE-SAT'D WATER	50	73
B		HYPALON	PANTASOTE	TCE-SAT'D WATER	50	77
C		HDPE	SCHLEGEL	TCE-SAT'D WATER	50	81
D		XR-5	SHELTER-RITE	TCE-SAT'D WATER	50	85
E		EPDM	CARLISLE	TCE-SAT'D WATER	50	89
F		NEOPRENE	CARLISLE	TCE-SAT'D WATER	50	93
X		Overlapping data points				





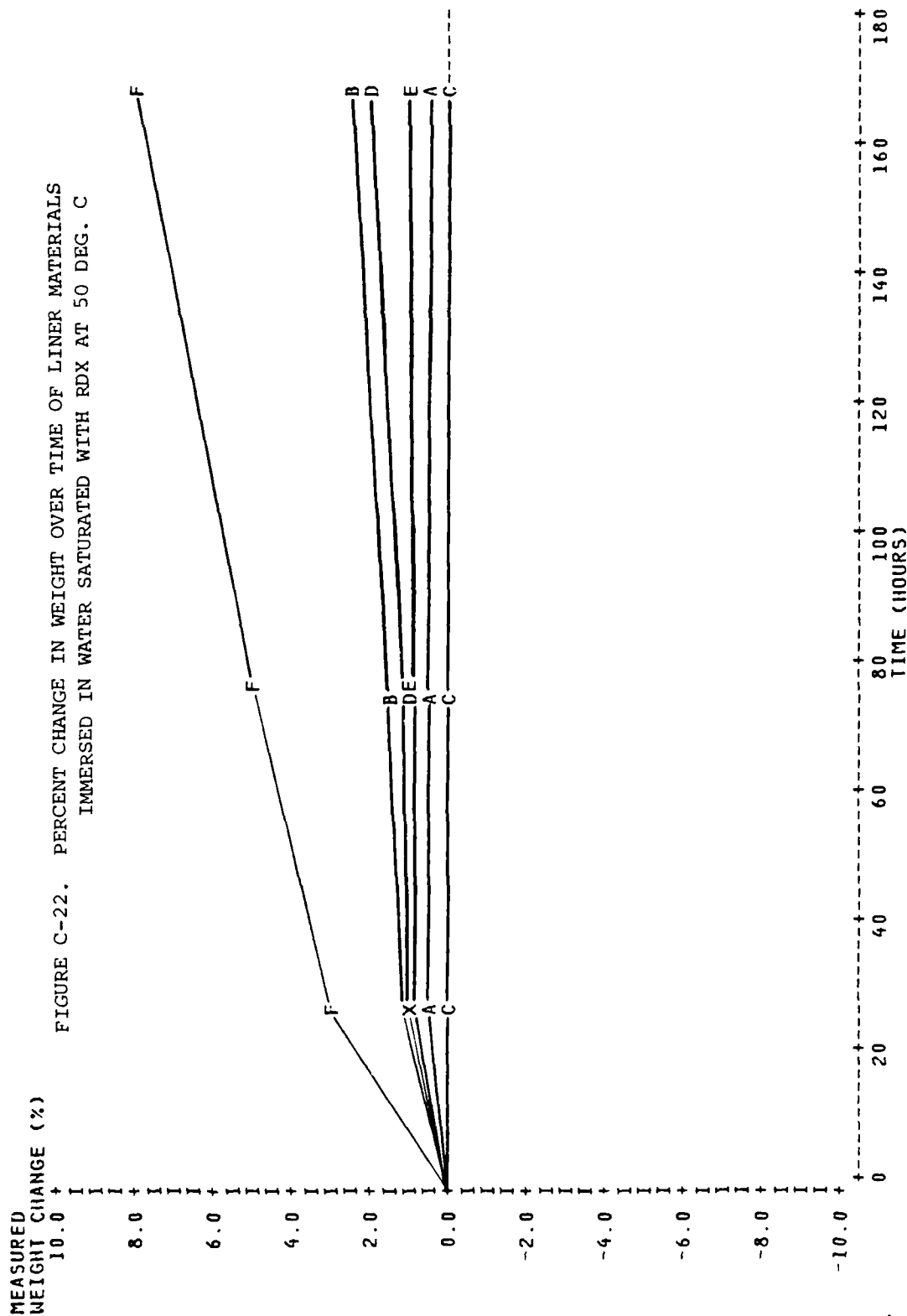
LEGEND:

SYMBOL	MATERIAL(S)	MAKER	CHEMICAL	TEMP	JAR
A	HYPALON	STEVENS	TNT-SAT'D WATER	50	72
B	HYPALON	PANTASOTE	TNT-SAT'D WATER	50	76
C	HDPE	SCHLEGEL	TNT-SAT'D WATER	50	80
D	XR-5	SHELIER-RITE	TNT-SAT'D WATER	50	84
E	EPDM	CARLISLE	TNT-SAT'D WATER	50	88
F	NEOPRENE	CARLISLE	TNT-SAT'D WATER	50	92
X	Overlapping data points				



LEGEND:

SYMBOL	MATERIAL(S)	MAKER	CHEMICAL	TEMP	JAR
A	PVC	PALCO	RDX-SAT'D WATER	50	133
B	PVC	PANTASOTE	RDX-SAT'D WATER	50	134
C	PVC-OR	PALCO	RDX-SAT'D WATER	50	135
D	PVC-OR	PANTASOTE	RDX-SAT'D WATER	50	136
E	CPE	PALCO	RDX-SAT'D WATER	50	137
F	CPE	PANTASOTE	RDX-SAT'D WATER	50	138
X	Overlapping data points				



LEGEND:	SYMBOL	MATERIAL(S)	MAKER	CHEMICAL	TEMP	JAR
	A	HYPALON	STEVENS	RDX-SAT'D WATER	50	139
	B	HYPALON	PANTASOTE	RDX-SAT'D WATER	50	140
	C	HDPE	SCHLEGEL	RDX-SAT'D WATER	50	141
	D	XR-5	SHELTER-RITE	RDX-SAT'D WATER	50	142
	E	EPDM	CARLISLE	RDX-SAT'D WATER	50	143
	F	NEOPRENE	CARLISLE	RDX-SAT'D WATER	50	144
	X	Overlapping data points				

APPENDIX D

TABULATIONS OF WEIGHT CHANGES AND ABSORBANCE

INDEX

<u>Table Number</u>	<u>Liner Type</u>	<u>Test Solution</u>
D-1	PVC (PVC/PVC-OR)	Unexposed; water
D-2	PVC (PVC/PVC-OR)	TNT; TCE
D-3	CPE/Hypalon	Unexposed; water
D-4	CPE/Hypalon	TNT; TCE
D-5	HDPE	Unexposed; water
D-6	HDPE	TCE; TNT
D-7	XR-5	Unexposed; water
D-8	NR-5	TNT; TCE
D-9	EPDM/Neoprene	Unexposed; water
D-10	EPDM/Neoprene	TNT; TCE
D-11	PVC, CPE, Hypalon, HDPE, XR-5, EPDM	RDX

TABLE D-1. PVC (PVC/PVC-OR)- AVERAGE WEIGHT CHANGE VALUES

TIME	PERCENT WEIGHT CHANGE			
	Unexposed 23°C n=12 ^a	Unexposed 50°C n=12	Distilled Water 23°C n=12	Distilled Water 50°C n=12
1 day	-0.21 (1.00) ^b n=11	-0.83 (0.52)	-0.68 (1.58)	-0.02 (0.62)
3 days	-0.02 (1.37)	-0.94 (0.64)	-0.60 (1.63) n=11	0.10 (0.60)
7 days	-1.23 (1.12)	-1.83 (0.67)	-1.53 (1.46)	-0.52 (1.17)
Dried (7 days)	-2.43 (1.09)	-1.88 (0.38)	-2.96 (1.70)	-1.73 (0.57)
Absorbance ^c	1.20 (0.69)	-0.04 (0.86)	1.44 (0.42)	1.21 (1.19)

^a n = Population size

^b Values in parentheses are standard deviations

^c Absorbance = $\frac{W_7 - W_D}{W_0}$

TABLE D-2. PVC (PVC/PVC-OR)- AVERAGE WEIGHT CHANGE VALUES

TIME	PERCENT WEIGHT CHANGE			
	TNT 50°C n=12 ^a	TCE-Sat'd Water 23°C n=12	TCE-Sat'd Water 50°C n=12	Water-Sat'd TCE 23°C n=12
1 day	0.24 (0.44) ^b	4.00 (1.83)	2.85 (1.54)	37.34 (13.19)
3 days	1.15 (0.79)	3.66 (1.48)	3.99 (1.49)	32.02 (8.22)
7 days	2.17 (1.38)	3.97 (1.60)	3.45 (1.12) n=11	30.11 (7.17)
Dried (7 days)	0.66 (0.25)	-2.18 (0.87)	-1.53 (0.85)	-22.56 (2.01)
Absorbance ^c	1.51 (1.28)	6.15 (1.38)	4.99 (1.18) n=11	52.67 (5.89)

^a n = Population size

^b values in parentheses are standard deviations

^c Absorbance = $\frac{W_7 - W_D}{W_0}$

TABLE D-3. CPE/HYPALON-AVERAGE WEIGHT CHANGE VALUES

TIME	PERCENT WEIGHT CHANGE					
	Unexposed 23°C CPE & Hypalon n=12 ^a	Unexposed 50°C CPE n=6	Unexposed 50°C Hypalon n=6	Distilled Water 23°C CPE & Hypalon n=12	Distilled Water 50°C CPE n=6	Distilled Water 50°C Hypalon n=6
1 day	0.03 (0.22) ^b	-0.43 (0.36)	-0.07 (0.31)	0.22 (0.22)	1.18 (0.30)	0.60 (0.66)
3 days	0.08 (0.22)	-0.75 (0.28)	-0.28 (0.28)	0.54 (0.29)	2.61 (0.30)	0.74 (0.74)
7 days	-0.17 (0.33)	-1.04 (0.25)	-0.28 (0.28)	0.84 (0.61)	4.52 (0.27)	1.43 (1.18)
Dried (7 days)	-0.34 (0.36)	-0.79 (0.10)	-0.09 (0.25)	-0.40 (0.50)	-0.02 (0.71)	-0.14 (0.17)
Absorbance ^c	0.17 (0.25)	-0.25 (0.18)	-0.18 (0.12)	1.24 (0.88)	4.54 (0.96)	1.57 (1.20)

^a n = Population size

^b Values in parentheses are standard deviations

^c Absorbance = $\frac{W_7 - W_D}{W_0}$

TABLE D-4. CPE/HYPALON-AVERAGE WEIGHT CHANGE VALUES

TIME	PERCENT WEIGHT CHANGE							
	TNT 50°C CPE n=6 ^a	TNT 50°C Hypalon n=6	TCE-Sat'd Water 50°C CPE n=6	TCE-Sat'd Water 50°C Hypalon n=6	TCE-Sat'd Water 23°C CPE & Hypalon n=9	TCE-Sat'd Water 23°C CPE n=3		
1 day	0.95 (1.06) ^b	0.77 (0.46)	5.52 (3.27)	8.39 (0.76)	2.22 (1.16)	8.90 (0.29)		
3 days	3.41 (0.16)	1.30 (0.34)	7.56 (2.28)	6.74 (0.94)	3.02 (1.18)	13.65 (0.79)		
7 days	6.85 (0.10)	2.33 (0.86)	10.40 (0.94)	6.99 (0.88)	3.64 (1.40)	16.11 (0.15)		
Dried (7 days)	2.44 (0.71)	0.75 (0.21)	1.60 (2.28)	-0.30 (0.39)	-0.50 (0.84)	0.93 (0.23)		
Absorbance ^c	4.41 (0.62)	1.58 (1.05)	8.81 (1.40)	7.31 (0.55)	4.14 (1.64)	15.17 (0.18)		

^a n = Population size

^b Values in parentheses are standard deviations

^c Absorbance = $\frac{W_1 - W_D}{W_0}$

TABLE D-5. HPDE-AVERAGE WEIGHT CHANGE VALUES

TIME	PERCENT WEIGHT CHANGE			
	Unexposed 23°C n=3 ^a	Unexposed 50°C n=3	Distilled Water 23°C n=3	Distilled Water 50°C n=3
1 day	0.08 (0.05) ^b	0.07 (0.06)	-0.02 (0.13)	0.12 (0.12)
3 days	0.06 (0.07)	0.08 (0.14)	0.27 (0.23)	0.15 (0.10)
7 days	0.20 (0.19)	-0.04 (0.02)	0.26 (0.09)	0.20 (0.05)
Dried (7 days)	-0.01 (0.04)	0.32 (0.11) n=2	-0.05 (0.08)	0.30 (0.11)
Absorbance ^c	0.21 (0.22)	-0.37 (0.13) n=2	0.30 (0.16)	-0.10 (0.06)

^a n = Population size

^b Values in parentheses are standard deviations

^c Absorbance = $\frac{W_7 - W_D}{W_0}$

TABLE D-6. HDPE-AVERAGE WEIGHT CHANGE VALUES

TIME	PERCENT WEIGHT CHANGE			
	TNT 50°C n=3 ^a	TCE-Sat'd Water 23°C n=3	TCE-Sat'd Water 50°C n=3	Water-Sat'd TCE 23°C n=3
1 day	0.04 (0.20) ^b	1.75 (0.14)	3.58 (0.11)	14.77 (0.32)
3 days	0.11 (0.12)	3.10 (0.14)	2.81 (0.19)	14.72 (0.13)
7 days	0.17 (0.15)	2.96 (0.10)	1.07 (0.03)	14.86 (0.29)
Dried (7 days)	0.16 (0.15)	0.44 (0.13)	0.46 (0.08)	0.24 (0.03)
Absorbance ^c	0.01 (0.05)	2.52 (0.09)	0.60 (0.09)	14.61 (0.32)

^a n = Population size

^b Values in parentheses are standard deviations

^c Absorbance = $\frac{W_7 - W_0}{W_0}$

TABLE D-7. XR-5-AVERAGE WEIGHT CHANGE VALUES

TIME	PERCENT WEIGHT CHANGE			
	Unexposed 23°C n=3 ^a	Unexposed 50°C n=3	Distilled Water 23°C n=3	Distilled Water 50°C n=3
1 day	-0.16 (0.07) ^b	-0.13 (0.08)	-0.26 (0.70)	0.60 (0.37)
3 days	0.56 (0.08)	-0.22 (0.27)	-0.34 (1.06)	1.30 (0.35)
7 days	-0.34 (0.12)	-0.26 (0.14)	0.05 (0.66)	1.74 (0.41)
Dried (7 days)	-0.47 (0.06)	-0.12 (0.23)	-0.88 (0.68)	-0.45 (0.24)
Absorbance ^c	0.13 (0.14)	-0.14 (0.21)	0.93 (0.10)	2.19 (0.17)

^a n = Population size

^b Values in parentheses are standard deviations

^c Absorbance = $\frac{W_7 - W_D}{W_0}$

TABLE D-8. XR-5-AVERAGE WEIGHT CHANGE VALUES

TIME	PERCENT WEIGHT CHANGE			
	TNT 50°C n=3 ^a	TCE-Sat'd Water 23°C n=3	TCE-Sat'd Water 50°C n=3	Water-Sat'd TCE 23°C n=3
1 day	0.79 (0.11) ^b	2.05 (0.61)	7.06 (0.31)	225.39 (5.35)
3 days	2.10 (0.10)	3.03 (0.38)	8.24 (0.60)	197.84 (9.86)
7 days	3.67 (0.28)	4.24 (0.53)	6.70 (0.11)	188.43 (1.83)
Dried (7 days)	1.06 (0.12)	-0.19 (0.57)	-0.74 (0.29)	-25.15 (0.55)
Absorbance ^c	2.61 (0.19)	4.43 (0.04)	7.43 (0.17)	213.57 (1.56)

^a n = Population size

^b Values in parentheses are standard deviations

^c Absorbance = $\frac{W_7 - W_D}{W_0}$

TABLE D-9. EPDM/NEOPRENE-AVERAGE WEIGHT CHANGE VALUES

TIME	PERCENT WEIGHT CHANGE			
	Unexposed 23°C n=6 ^a	Unexposed 50°C n=6	Distilled Water 23°C n=6	Distilled Water 50°C n=6
1 day	-0.34 (0.22) ^b n=5	-0.25 (0.26)	0.20 (0.15)	1.49 (0.96)
3 days	-0.44 (0.18)	-0.37 (0.15)	0.38 (0.19)	2.61 (1.91)
7 days	-0.46 (0.20)	-0.46 (0.27)	1.31 (0.60)	4.11 (3.12)
Dried (7 days)	-0.48 (0.18)	-0.33 (0.22)	-0.18 (0.12)	0.25 (0.35)
Absorbance ^c	0.02 (0.06)	-0.14 (0.16)	1.49 (0.65)	3.86 (2.82)

^a n = Population size

^b Values in parentheses are standard deviations

^c Absorbance = $\frac{W_7 - W_D}{W_0}$

TABLE D-10. EPDM/NEOPRENE-AVERAGE WEIGHT CHANGE VALUES

TIME	PERCENT WEIGHT CHANGE			
	TNT 50°C n=6 ^a	TCE-Sat'd Water 23°C n=6	TCE-Sat'd Water 50°C n=6	Water-Sat'd TCE 23°C n=6
1 day	1.91 (1.06) ^b	4.09 (1.66)	4.46 (1.33)	137.17 (12.61)
3 days	3.51 (2.31)	4.89 (1.13)	6.53 (2.05)	141.02 (11.25)
7 days	5.73 (4.18)	6.09 (0.43)	9.90 (0.46)	140.86 (9.43)
Dried (7 days)	1.46 (0.94)	-0.17 (0.19)	0.71 (0.45)	-15.88 (5.21)
Absorbance ^c	4.28 (3.26)	6.26 (0.56)	9.19 (0.14)	156.74 (4.57)

^a n = Population size

^b values in parentheses are standard deviations

^c Absorbance = $\frac{W_7 - W_D}{W_0}$

TABLE D-11. AVERAGE WEIGHT CHANGE VALUES OF LINER GROUPS
IMMERSED IN RDX SATURATED WATER AT 50°C

TIME	PERCENT WEIGHT CHANGE			
	PVC n=12 ^a	CPE n=6	Hypalon (Stevens) n=3	Hypalon (Pantasote) n=3
1 days	-0.45 (1.36) ^b	+1.88 (0.19)	+0.33 (0.08)	+1.24 (0.07)
3 days	-1.10 (1.42)	+3.31 (0.30)	+0.37 (0.05)	+1.66 (0.08)
7 days	-1.44 (1.84)	+5.06 (0.28)	+0.65 (0.03)	+2.57 (0.11)
Dried (7 days)	-5.23 (1.34)	-0.74 (0.55)	-0.57 (0.02)	-0.36 (0.04)
Absorbance ^c	+3.79 (0.88)	+5.80 (0.61)	+1.22 (0.02)	+2.93 (0.09)

^a n = Population size

^b values in parentheses are standard deviations

^c Absorbance = $\frac{W_7 - W_D}{W_0}$

TABLE D-11 (Continued). AVERAGE WEIGHT CHANGE VALUES OF LINER GROUPS
IMMERSED IN RDX SATURATED WATER AT 50°C

TIME	PERCENT WEIGHT CHANGE			
	HDPE n=3 ^a	XR-5 n=3	EPDM n=3	Neoprene n=3
1 days	+0.02 (0.06) ^b	+0.88 (0.36)	+0.95 (0.27)	+3.09 (0.16)
3 days	+0.01 (0.08)	+1.24 (0.12)	+0.77 (0.17)	+4.97 (0.16)
7 days	+0.07 (0.11)	+1.84 (0.22)	+1.04 (0.12)	+7.95 (0.20)
Dried (7 days)	-0.19 (0.04)	-1.40 (0.08)	-0.50 (0.11)	+1.33 (0.06)
Absorbance ^c	+0.26 (0.12)	+3.24 (0.25)	+1.53 (0.20)	+6.61 (0.14)

^a n = Population size

^b Values in parentheses are standard deviations

^c Absorbance = $\frac{W_7 - W_D}{W_0}$

APPENDIX E
LINER SCREENING TEST DATA FORMS

INDEX

E-1	Data Sheet
E-2	Data Summary Sheet
E-3	Test Result Sheet

ENGINEERING-SCIENCE
 JSATHAMA LINER SCREENING TEST
 DATA SHEET (E-1)

Liner Material: _____ Temperature: _____
 Chemical: _____
 Start: Date _____ Time: _____ Concentration: _____ Test Result Sheet:

Sample Point	Exposure Time (hrs)	Weight (gm)	Thickness (in.)	Width (in.)			Length (in.)		Appearance
Initial 1 day 3 day 7 day Final									
Initial 1 day 3 day 7 day Final									
Initial 1 day 3 day 7 day Final									

E-1

ENGINEERING-SCIENCE
USATHAMA LINER SCREENING TEST
DATA SUMMARY SHEET (E-2)

Liner Material: _____ Temperature: _____
Chemical: _____
Start: Date _____ Time: _____ Concentration: _____ Test Result Sheet: _____

Sample No.		Sample Point	Exposure Time (hrs)	Weight (gm)	Average Thickness (in.)	Average Width (in.)	Average Length (in.)	Volume (in. ³)	Appearance
		Initial							
		1 day							
		3 day							
		7 day							
		Final							
		Initial							
		1 day							
		3 day							
		7 day							
		Final							
		Initial							
		1 day							
		3 day							
		7 day							
		Final							

E-2

ENGINEERING-SCIENCE
USATHAMA LINER SCREENING TEST
TEST RESULT SHEET (E-3)

Liner Material _____ Chemical _____ Temperature _____

Start Date _____ Time _____ Concentration _____

Sample No.	Initial Weight	Percent Weight Change				Percent Absorbance
		____ hrs	____ hrs	____ hrs	Final ____ hrs	
AVERAGE						

Sample No.	Initial Volume	Percent Change in Volume				Percent Swell
		____ hrs	____ hrs	____ hrs	Final ____ hrs	
AVERAGE						

Jar Number _____

Page Number _____

